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TRANSACTIONS

of the
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Vol. 1

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BUSINESS PROSPECTS APPEAR BRIGHTER

That business is on the upgrade may be an interpretation of recent trade developments. While these developments are not sufficiently definite to make this statement an assurance, the general tendency seems to point to a gradual revival of industrial activity on a small scale. After months of inactivity, markets particularly in the iron and steel trade are beginning to look up. No one given event or condition can be assigned as a reason for this improvement, but a number of factors working together are exerting a greater or lesser influence on business in general.

Of greatest significance perhaps is the recent announcement of the government that \$500,000,000 will be paid to the railroads of the country. That this action on the part of the government will materially strengthen the buying power of the railroads can not be questioned. Practically all of the roads of the country are in narrow financial straits and as a result have almost completely disappeared from the market as buyers. And the volume of business placed by railroads in normal times is considerable. All roads are needing new equipment and extensive repairs for present rolling stock and equipment, but with credit relations already stretched to the limit, further purchases were not to be considered. Thus the government's announcement of intended financial relief came as a welcome to the roads and industry in general and as the relief becomes more certain day by day, the railroads again have begun to place inquiries for materials and even to close on some business which has been hanging fire. Some authorities on economic problems have declared that the return of the railroads to buying would serve as the first step to the resumption of all business and as to how well founded this belief has been is about to be ascertained.

Easing of the financial market during the past few weeks has also served as a stimulant to business and is another factor entering into the complex order of events. Part of the improvement in financial conditions is a result of the sidetracking of the soldiers' bonus bill by the senate together with recent developments in the armament policy of the country and a general economy policy being placed in effect by the administration. Each week shows increase in the reserve ratio of the federal reserve system, the figure standing over 61 per cent compared with a dangerous 43 per cent one year ago. The coming harvest of large and more cheaply produced crops will enable farmers to meet their obligations and to have a good spending power besides.

During the week of July 11, iron and steel markets were somewhat improved over what they had been for some time. While the increase in business was not of large volume, the general tone was better.

Some quantities of goods were purchased and inquiries were placed in larger numbers. Labor gradually is adjusting itself to the new conditions both as regards wages and efficiency, and is exerting some influence in the stabilizing of the present industrial unrest. All in all, indications are that the low point has been reached if not well passed but the developments of the next few weeks must be awaited to prove whether this is actually true.

FATIGUE STUDY OF STEEL IS IMPORTANT

During recent years considerable attention has been given to the fatigue strength of metals or the number of vibrations or repeated stresses which certain parts will withstand before failure will occur. Data upon this subject is of great importance to engineers and builders of machinery and equipment in order that human life will not be endangered by sudden failure of highly stressed parts. Elevator cables, bridge members and automobile and airplane parts are properly classified under this head. Crystallization of the metal has been assigned as a frequent cause of failure but scientific research has proved this conception to be incorrect. In a study of fatigue strength, the problem must be attacked from several angles including the composition of the steel and the relation to heat treatment.

On other pages of this issue appears a comprehensive discussion of the effect of heat treatment on the fatigue strength of steel. In this particular series of investigations the parts tested were automobile leaf springs and the material high carbon steel. Although limited to one type of steel and to one product, the results should serve as a guide in undertaking further study of fatigue characteristics. The author draws four main conclusions which might well be emphasized, namely: 1. There is one certain quenching temperature which yields maximum fatigue strength and in the case of high carbon steel, this temperature corresponds closely to the A_{cm} point; 2. The drawing temperature has a decided effect on the fatigue strength and there is one drawing temperature which yields maximum fatigue strength; 3. Experimental evidence strongly indicates that decarburization has a very detrimental effect on fatigue strength; and 4. Duplication of the regular heat treatment will not cure fatigue but on the contrary will hasten failure of such parts that have already been subjected to repeated stresses.

These conclusions, which were made as a result of extensive work are brief but definite and add to the knowledge of fatigue phenomena. They should pave the way for research as to what may be expected from the many types of alloy steel.

REDUCED RATES TO INDIANAPOLIS

We are very glad to announce that the railroads of the country, through the Central Passenger Association, have granted fare and a half round trip for members of the Society and their dependents, for the Indianapolis Convention and Exhibition, Sept. 19 to 24. A large number of members and guests are always in attendance at this Convention, thus the railroads unanimously decided to recognize the Society to the extent of granting the fare and a half for the round trip.

There are certain restrictions placed on the purchase of these tickets inasmuch as an identification must be presented to the ticket agent for the

purchase of the round trip ticket. This identification certificate will be mailed to all the members of the Society before the first of September.

HOTELS IN INDIANAPOLIS

Indianapolis has promised to provide our guests with excellent accommodations as far as hotels are concerned, and through the efforts of J. E. Burns Jr., chairman of the Hotel Committee, a list of hotels is given below.

All persons in attendance at Indianapolis will make their own reservations direct with the managers of the hotels, and it is advisable that the members take this precaution. When making reservations give date of arrival, kind of room desired, and price you wish to pay, and what is most important, request the hotel manager to answer your letter repeating the reservation. Then take the letter with you to present to the hotel clerk at Indianapolis when you register.

This precaution taken now may avoid serious difficulty at the time of the Convention.

It is recommended that reservations be made immediately.

The list of hotels follows:

Hotels	Capacity	Rates
Brevort Hotel	94 Rooms	\$1.25 to \$3.00 per day
New Colonial Hotel	92 "	\$2.00 to \$4.00 " "
New Denison Hotel	175 "	\$1.25 to \$2.00 " "
Edward Hotel	150 "	\$1.25 to \$4.00 " "
Grand Hotel	76 "	\$1.50 to \$3.00 " "
Hotel Lincoln	100 "	\$2.00 up " "
Lorraine Hotel	90 "	\$1.00 to \$4.50 " "
New Morton Hotel	65 "	\$1.50 to \$5.00 " "
Great Eastern Hotel	126 "	\$1.25 to \$3.00 " "
Stubbins Hotel	75 "	\$1.00 to \$4.50 " "
Hotel Severin	400 "	\$2.50 to \$8.00 " "
Hotel Washington	300 "	\$2.50 to \$4.00 " "
Hotel Williams	92 "	\$1.75 up " "
Terminal Hotel	45 "	\$1.50 up " "
Ohio Hotel	40 "	\$1.50 up " "
Claypool Hotel	700 "	\$2.50 up " "
Frohman Hotel	80 "	not over \$3.50 " "
Haugh Hotel	60 "	" " " " "
Linden Hotel	250 "	" " " " "
Majestic Hotel	59 "	" " " " "
Roosevelt Hotel	187 "	" " " " "
Royal Hotel	85 "	" " " " "

SPORT IN INDIANAPOLIS

George Desautels, chairman of the Entertainment Committee, is planning to have an inter-city tennis tournament, and also an inter-city golf tournament. Any exhibitor, member or guest from the various cities may enter these tournaments. Trophies will be awarded the winning tennis team, and to the best golfer. The course at Highland Golf and Country Club has been secured for the golf tournament. This course represents the sportiest and best in the United States, and it will be a treat to every golfer to try out the excellent course.

Not only will there be prizes for the individuals and teams turning in the lowest score, but there will also be prizes for the dubs. So do not permit the fact that you are no low medal artist prevent you from bringing your golf sticks along and enjoying the game. If you're going to bring your golf sticks and tennis rackets along, communicate with George Desautels, Imperial Drop Forge Co., Indianapolis.

SPACE RESERVED AT INDIANAPOLIS CONVENTION

The latest list of exhibitors whose products will be an exhibition at the convention follows:

Alcorn, Blackhouse Co., electric furnaces in operation.....	3
Charles Englehard, temperature control and recording instruments in operation.....	4
Surface Combustion Co.	5
Bristol Co., recording instruments in operation	6
Smith Gas Engineering Co., producer gas machines in operation.....	7
George J. Hagen Co., oil and gas furnaces in operation	8 9
Westinghouse Elec. & Mfg. Co., electric appliances in operation.....	A-B
Brown Instrument Co., recording instruments in operation.....	17
Midvale Steel & Ordnance Co., operating exhibit of steels.....	18
Indianapolis Drop Forging Co., forgings in operation.....	19
Eaton Electric Furnace Co., electric furnaces in operation.....	20
Calorizing Co. of Pittsburgh, calorizing process in operation	21
Deeds Commercial Laboratories, carbonizing compounds in operation.....	22
Leeds & Northrup Co., electric furnaces and pyrometers in operation.....	36-23
Bausch & Lomb Optical Co., metallographic instruments in operation.....	24
Tate-Jones Co., Inc., furnaces	25
Armstrong Cork & Insulating Co., insulating materials	27
Taylor Instrument Co., in operation	28
Marschke Mfg. Co., electric grinders and buffers in operation	31
Quigley Furnace Specialties Co., furnace specialties in operation.....	32
Hoskins Mfg. Co., electric furnaces and recording instruments in operation..	33
Simonds Mfg. Co., steels and saws in operation.....	34
General Electric Co., electric furnaces in operation	35
William Ganschow Co., gears	37
Bethlehem Steel Co., steels	57-44
Spencer Turbine Co., blowers in operation	45
Driver Harris Co., alloy pots and boxes.....	49
Crucible Steel Co. of America, steels	63-51-50
Electric Steel Co. of Indiana, castings	55
Penton Publishing Co., "The Iron Trade Review"	58
Witherow Steel Co., continuous die forming	62
Halcomb Steel Co., steels.....	82-69
Atlas Crucible Steel Co., steels	83-70
Bell & Gossett, case hardening materials	74
The Iron Age, publications	75
Deeds & Chapin, "Cinch" cement	81
Case Hardening Service Co., carburizing compounds	87
General Alloys Co., alloy pots and boxes	107-94
Electrical Refractories Co., refractory materials	95
W. S. Rockwell Co., oil and gas furnace	99
Electric Alloy Steel Co., alloy steels	100
Colonial Steel Co., steels	108
Herman A. Holz, Inc., metallurgical equipment	119
Bureau of Standards, research work	124
Imperial Drop Forging Co., forgings	120
Vanadium Alloy Steel Co., steels	125
Heppenstall Knife & Forge Co., die blocks	126
E. C. Atkins Mfg. Co., metal saws and cutting machines	153
Mahr. Mfg. Co., furnaces	Unassigned
Dearborn Chemical Co., oils and rust preventatives	Unassigned
Central Steel Co., alloy steel	38
Celite Products Co., insulating materials in operation	39
Wilson-Maeulen Co.	41

**EFFECT OF HEAT TREATMENT ON THE FATIGUE-STRENGTH
OF STEEL**

By E. P. Stenger* and B. H. Stenger**

(A Paper Presented at Philadelphia Convention)

In the engineering profession, it is a commonly known fact, that metallic parts subjected to vibratory or repeated stresses often fail due to the phenomenon of fatigue or "crystallization", as it is sometimes incorrectly termed. All are familiar with the manner in which a lad without pliers breaks a piece of ordinary soft wire. He will bend it back and forth until finally the wire breaks at the point of highest stress. This is a fatigue failure. In this case, however, the stress induced by bending is high, while the fatigue strength of the material is low, therefore only a small number of reversals are necessary to cause breakage.

By fatigue strength is meant the resistance that a metal offers to alternating or repeated stresses. The endurance of one metal as compared to another, or of the same metal when differently treated, has been found to vary greatly. By some authorities the numerical value of the fatigue strength has been taken to mean the stress at which an infinite number of repetitions does not cause failure; by others it is taken as a comparative figure representing the number of repetitions required to produce failure at a given stress. Throughout this paper the term fatigue strength is used in the latter sense. The object of this paper was to determine the effect which heat treatment exerts on the fatigue strength of steel and the work was carried out in connection with practical problems arising in the design, manufacture, and use of automobile leaf springs.

In practice many parts are subjected to repeated or alternating stresses, but these stresses are in general comparatively low and when the material is of proper quality many million, and sometimes billions, of repetitions are necessary to cause failure. In automotive vehicles, parts such as the steering lever, spindle, springs, frame, crankshaft, piston rod, etc., are subjected to repeated stresses and failure of these parts is often due to fatigue. On steam locomotives such parts as the driving axle, crank pin, connecting rod, etc., are subjected to fatigue stresses. Many other parts such as shafting, elevator cables, bridge members and in general all objects which carry live loads of high amplitude are likewise subjected to repeated stresses and sometimes fail for this reason.

Failures through fatigue generally occur suddenly and without warning and are therefore of the most dangerous character. Such failures, under normal stress, show no deformation at the break and in this and the preceding respect resemble those occurring in brittle material. Indeed, according to Bielby's theory, a hard brittle amorphous material forms in the planes of slip which are produced within the crystals by repeated stresses. Many excellent chapters have been written by Howe, Moore, Bairstow, Rosenhain and others describing the minute and microscopic internal changes which take place within the metallic crystals while undergoing repeated stresses, and therefore, this phase of the subject will herein receive little consideration. Attention will be given primarily to quantitative results.

*Metallurgical engineer, Thompson & Black, accountants and engineers, New York and Detroit.

**Metallurgist, Sheldon Axle & Spring Co., Wilkes-Barre, Pa.

Although fatigue failures resembled those occurring in brittle material, a different type of fracture is generally revealed. The fracture of brittle materials, as is commonly known, is clean cut and of a uniform texture, while on the other hand, the fracture of parts failing through fatigue frequently reveal a non-uniform texture as shown in Figs. 2 and 3.

In examining these fractures it is seen that they are made up of two distinct areas; the one revealing an apparently fine grain, the other showing a comparatively coarse grain, thus simulating the fracture which might result from nonuniformity of the quenching temperature. However, if such parts are examined by means of the microscope, it is found that polished and etched specimens reveal a perfectly homogeneous grain structure throughout the whole of the section. Since the areas, which to the naked eye seem to have a refined grain, are found almost invariably at the points of maximum stress, it is thought that this apparently fine-grained material is caused by the grinding action of the debris resulting from the destruction of the previously angular crystals due to the move-

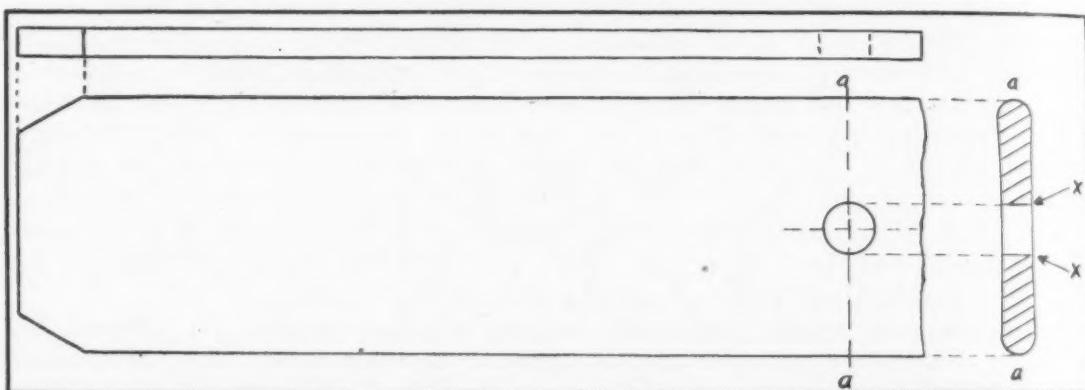


Fig. 1—Sketch of Automobile Spring Leaf Used in Making Tests

ment of the crystallites relative to one another under the action of repeated stresses. These fractures therefore show the absurdity of speaking of such failures as having been due to crystallization. By crystallization is meant the formation or growth of crystals and here it is seen that the action of repeated stresses is to destroy the existing crystals and not to aid in their formation.

Attention is invited to the close similarity existing between the fractures obtained from the laboratory fatigue test and those obtained from service. For instance, comparing fracture *b* to fracture *c*, it is seen that in both cases failure evidently started at the point marked and from there gradually grew until the fissure had spread over the entire fine-grained area, at which time the stress became so highly localized as to cause failure throughout the remainder of the section. There is one difference, however, which is often noted between the failures occurring in service and those obtained in the laboratory test for fatigue. Although in both cases the fissures are seen to grow radially from a central point *Z*, still the service fractures are marked by concentric lines as is most plainly shown in fractures *g* and *h*. It is very probable that these concentric lines are caused by the oft repeated impact blows of small magnitude which are met with in service, while in the laboratory test for fatigue, strength impact is completely lacking.

EFFECT OF HEAT TREATMENT ON THE FATIGUE
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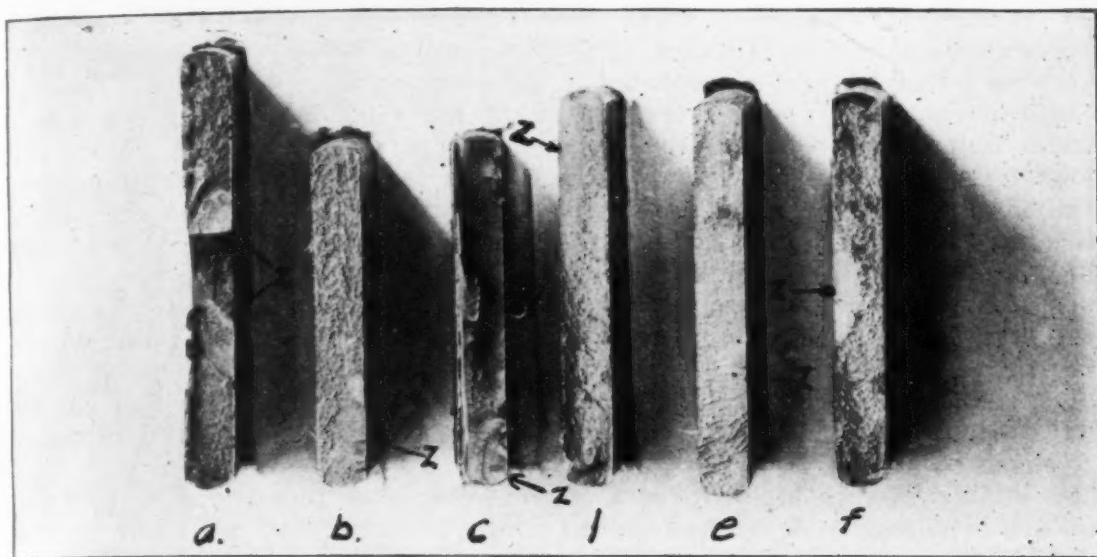


Fig. 2—Fatigue Fractures of Specimens Shown in Fig. 1. (a) Leaf Spring Which Failed in Service Showing Fracture through Center-Bolt Hole. (b) Carbon Steel Spring Which Failed through Fatigue in Spring Vibratory Machine. (c) Chrome-Vanadium Spring Which Failed After Six Months' Service. (d) Silico-Manganese Spring Steel After Failure in Laboratory Test for Fatigue Strength. (e) and (f) Carbon Spring Steel After Failure in Laboratory Test for Fatigue Strength

Before dealing with the influence which heat treatment exerts on fatigue strength, it will be well to review briefly what has been learned concerning this property in the past. Although the first studies of fatigue failures were made over half a century ago and although a great many investigators have devoted much time to problems concerned with the endurance of metals, yet because of length of time required to make the test for fatigue strength and also because of the difficulty of obtaining consistent results, our knowledge concerning the laws governing this phenomenon has made very slow progress.

The earliest and most extensive series of fatigue tests are those made

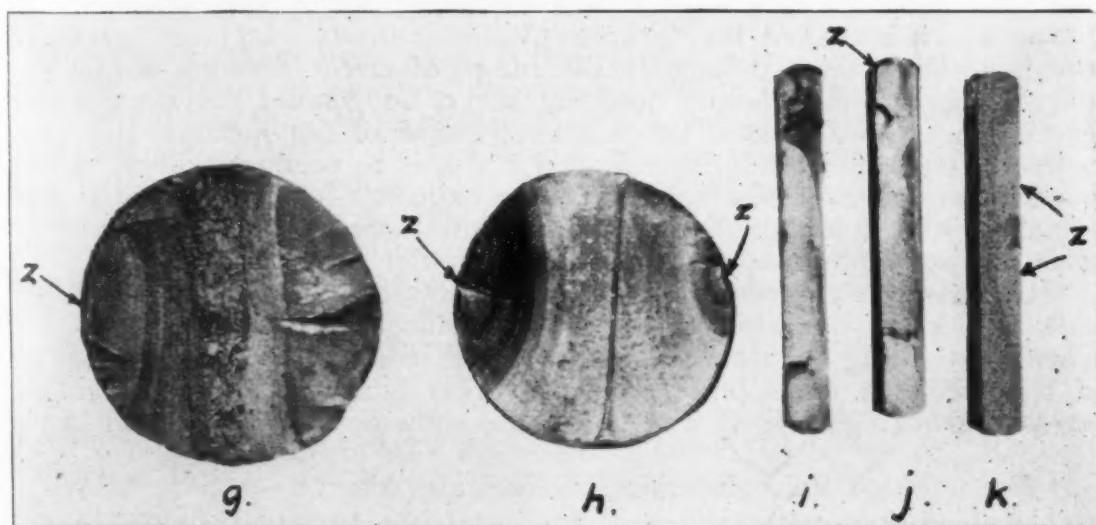


Fig. 3—Illustrations of Fatigue Fractures. (g) and (h) Chrome-Nickel Steering Levers Taken from Trucks After Failure in Service. (i) and (j) Chrome-Nickel-Molybdenum Spring Steel After Failure in Laboratory Test for Fatigue Strength. (k) Carbon Spring Steel After Failure in Laboratory Test for Fatigue Strength. Dark Spot in Center of Area of Localization is Due to Brinell Impression Made at That Point

by Wohler from 1858 to 1870. His experiments proved that iron and steel eventually will fail at a unit stress much below the ordinarily determined elastic limit if repeated a sufficient number of times. The results of some of Wohler's tests showing the relation between the maximum unit fiber stress and the number of repetitions to cause failure are shown in Fig. 4 in the form of a curve. It is seen from this figure that the number of repetitions to cause failure rapidly increase as the stress becomes lower and that at low stresses approaches infinity. When such data are plotted to logarithmic co-ordinates the curves become very nearly straight lines as is shown in Fig. 5. The special feature to be noted in this figure is that these curves do not change direction at the point where the nominal unit stress is equal to the ordinarily determined elastic limit of the material. By later researches of Upton and Lewis¹ such curves have been found to continue as a straight line almost to the ultimate strength.

Wohler's work also proves that the number of repetitions to produce failure is primarily dependent on the range of stress and not alone on the maximum unit stress. By range of stress is meant algebraic difference between the maximum and minimum stress applied. The range of stress at which the number of repetitions to produce failure becomes infinite is termed the limiting endurance range and this range was found to become more narrow as the maximum unit stress approached the ultimate strength.

Fig. 6, reproduced from Unwin's "Testing of Materials of Construction", shows in diagrammatical form the important conclusions concerning the limiting endurance range derived from Wohler's work. Those to whom the figure is not clear are referred to Unwin's book where a good description of Wohler's work is given. The work of Wohler was repeated and entirely supported by the later researches of Spangenberg, Bauschinger, Bairstow and several other careful investigators. From his work Bauschinger concluded that under repeated stress the material assumed new and variable elastic limits, the numerical value of which depended upon the nature of the repeated stresses. These limits he termed the "natural" elastic limits as compared to the ordinarily determined elastic limits which he called the "primitive" elastic limits. He then advanced the hypothesis that so long as the range of stress remains within the natural elastic limits failure does not occur, but should the stress range exceed the natural elastic limits then because of the inelastic behavior, work is done, the cumulative effect of which is to produce failure. Later experiments by Bairstow confirmed Bauschinger's hypothesis and it was found by him that the "natural elastic limits" correspond almost exactly with limiting endurance range found by Wohler.

Comparatively recent researches by Stromeier² also lends considerable support to Bauschinger's hypothesis since his results indicate that when the limiting endurance range is not exceeded, no perceptible heating of the specimen takes place. On the other hand, at higher ranges of stress the heat generated was noticeable showing that work was being done.

The work of other investigators indicates that:

1. The fatigue strength is not influenced by the speed of repetitions up to 2,000 reversals per minute. Also that rest and intermittent an-

¹American Machinist, Oct. 17 and 27, 1912.

²Proceedings Royal Society, Vol. A 90, page 411, 1914.

nealing at temperature below the Ac_1 point does not increase the endurance of unhardened steel.

2. Cold rolling increases the fatigue strength while on the other hand cold drawing seems to lower it.

3. Fatigue strength increases with the temperature at which the piece is tested up to between 300 and 400 degrees Cent. and thereafter rapidly falls off.

4. The fatigue strength increases with the carbon content up to eutectoid proportions and thereafter diminishes.

Some of the best authorities are still at variance concerning some of the points enumerated in the foregoing and more research work is needed to prove some of these statements. This holds especially for the effect of overstrain, for instance, No. 2.

The shape of a part or of a structural members has a very important bearing on fatigue strength. This influence, however, is not due primarily to the shape but it is brought about through nonuniform distribution and hence localization of stress. In many cases the formulas now used for calculating stress are very misleading. Their derivation has been based on plain and uniform sections in which the stress is uniformly distributed and for such apply with reasonable accuracy. However, the engineer for lack of any better often applies these formulas to nonuniform sections and irregular shapes in which the stress becomes concentrated at certain points. Holes, sharp corners and sudden changes of outline tend to localize the stress and the actual value at these points is often several hundred per cent greater than is shown by the stress formulas at present used for designing purposes. Therefore the repetitions of stress that such members can withstand are comparatively few in spite of the low nominal unit stress. The researches of Stanton and Bairstow³ show that the relative values of fatigue strength are about as follows: Rounded fillets, 100; standard screw thread, 70; sharp corners, 50.

In our own experiments with spring steel it was interesting to find that even very slight changes in the shape of the section have most startling effect on the fatigue strength as is clearly shown in Fig. 7. Here it is seen that the center bolt hole reduces the fatigue strength of that section by over 50 per cent. Fig. 1 illustrates a fracture passing through the center bolt hole of a spring leaf which failed in service as a result of fatigue. It shows that the stress becomes localized at the edge of the hole at the point marked *x*. In the laboratory tests conducted on punched plates, an exact duplication of localization of stress occurred at these points. This is the reason why the axle clips of an automobile should constantly be kept tight so that the maximum stress in the spring is made to act at the edge of the spring seat and not permitted to localize at the center bolt hole as it does when the axle clips are loose.

In another case it was found that the fatigue strength was increased several hundred per cent by grinding the concavity out of spring steel as is shown by *C* of Fig. 7. In this sketch the concavity is grossly exaggerated for it is so slight that most persons fail to observe it and assume that spring steel is of rectangular section. Although in the case of *C*, the difference in shape has considerable to do with the increase in fatigue strength, still it is felt that the better conditions of the surface and of the extreme fibers are the paramount factor making for the enormous increase. During heat treatment and previous operations, the ex-

³Engineering (London), Vol. 83, page 505, 1907.

treme fibers are often impaired due to the action of the hot gases on the surface. Under repeated stresses the extreme fibers generally fail first and after this occurs, complete rupture soon follows. Therefore, if the extreme fibers are decarburized or otherwise impaired during the heating operations, it follows that the fatigue strength would be greatly reduced. However, the detrimental effects due to such causes can be completely overcome by removing the surface layer through grinding or otherwise, and this is probably the chief reason why C of Fig. 7 gave such good results as compared to B. What portion of the increase in C of Fig. 7 is due to each of the two influencing factors, namely, change of shape and removal of surface layer, will be determined by further experiments.

As yet a completed and systematic study of the effect of heat treatment on the fatigue strength of steel has not been recorded. In reviewing the technical literature, it is found that the data pertaining to this subject are very meager and are of a miscellaneous character representing the results of many investigations in which different methods of testing and different types of testing machines and test specimens were used. It is therefore difficult to properly correlate this data. Gardner, Moore, McAdams and Kommers have performed valuable work in connection with the effect of heat treatment on fatigue and their experiments will be discussed later in connection with the conclusion drawn from our own work.

In the present experiments carbon spring steel was used which had the following composition: Carbon 1.03; manganese 0.45; sulphur, 0.025; phosphorus 0.026. Bars of this steel 18 inches in length, 2 inches wide and about 9/32-inch thick were quenched in oil at 100 degrees Fahr. from 1300, 1400, 1500, 1600 and 1700 degrees Fahr. Test bars quenched at each of the foregoing temperatures were drawn at 450, 600, 800, 850, 900, 950, 1000 and 1050 degrees Fahr. Both tension and fatigue tests were made for every combination of heat treatments, the average of three tests

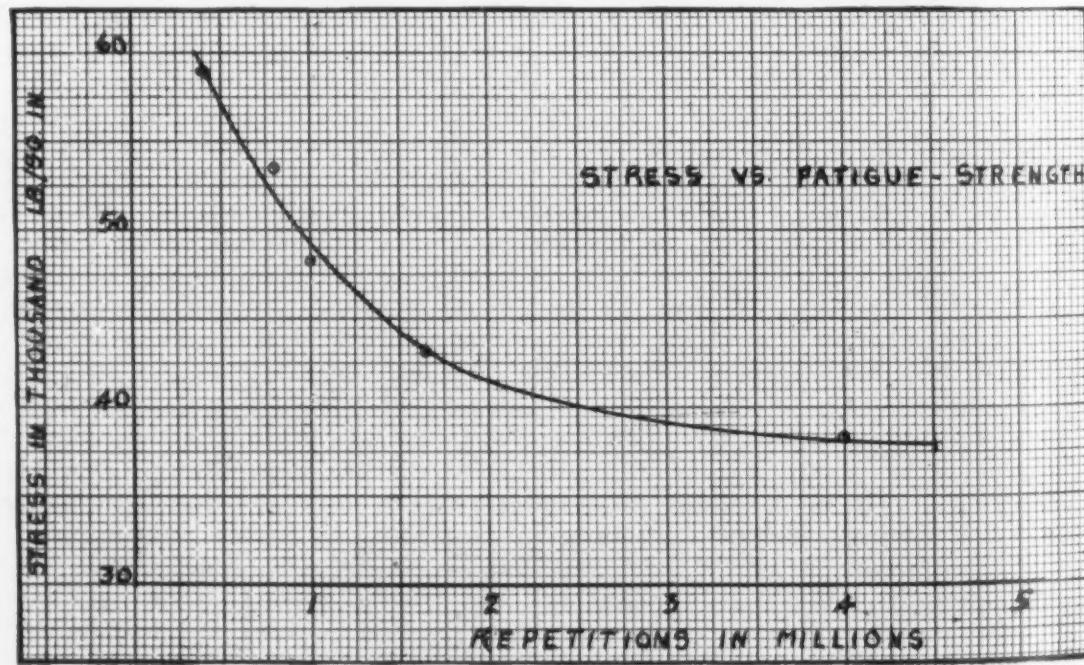


Fig. 4—Fatigue Test on Axle Steel by Wohler

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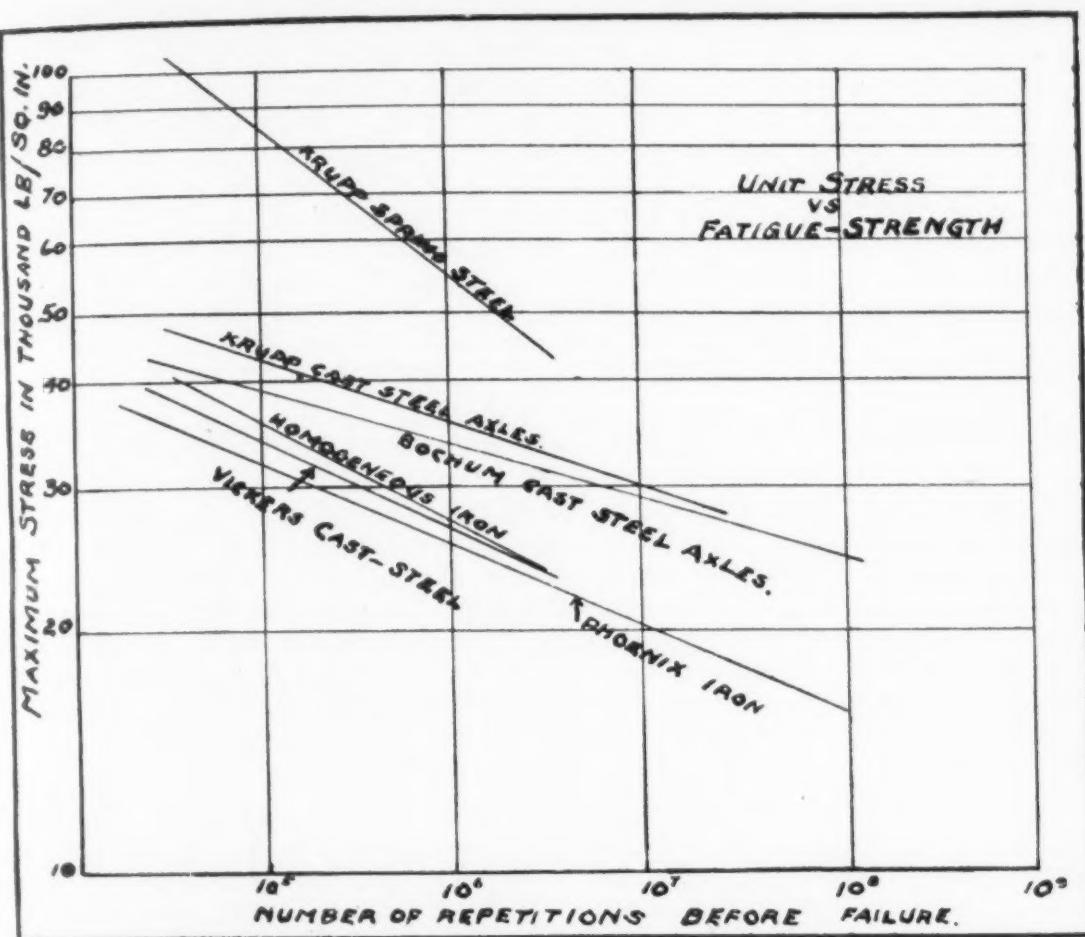


Fig. 5—Wohler's Tests on Various Steels

being used to establish each point. This means that in all a total of 120 fatigue and as many more tensile tests were made.

The heat treatment was carried out carefully in an electric muffle furnace in which the temperature was brought up rather quickly to that desired for quenching. The rate of heating can be judged by the curve taken from the recording pyrometer shown in Fig. 15. The total time in the furnace was about 50 minutes, and the quenching temperature was held for 15 minutes in each case. Three fatigue and three tensile specimens were removed from the furnace and quenched in oil simultaneously by means of a specially constructed rack. The rate of cooling was hastened by agitating the oil by movement of the rack. After the bars had become cold, they were removed from the oil and then carefully heated in the electric muffle furnace to the drawing temperature. Heat treated bars were then carefully ground to size and tested in tension or for fatigue strength. The thickness of the test specimens for the fatigue test was held to within the limits of plus or minus 0.001 inch.

For testing the fatigue strength a vibratory machine was used, in which the nominal unit stress as calculated by the deflection formula fluctuated from 0 to 150,000 pounds per square inch at the rate of 550 times per minute. In this machine the test specimen acts as a cantilever beam, one end being clamped tight while at the other, the load is applied causing deflection in one direction only. The number of repetitions

were obtained by an automatic counter and the end point of the test was easily detected by the loud report emitted by the bar upon failure.

In testing alloy steel it has been noted that failure is not accompanied by noise except in very hard specimens and that it takes place more gradually so that the end point is difficult to determine. If the fractures illustrated in Figs. 2 and 3 are examined, it is seen that the areas of localization in the case of alloy steels cover a larger portion of the section than in the case of carbon steel. Indeed in the case of fracture *h* it is seen that this chromium-nickel steel held to the last fiber. In carbon steel the failure is very abrupt while in the alloy steels the fractures are of a more progressive nature and therefore failure does not occur so suddenly.

The results of this investigation are shown in the form of curves in Figs. 8 to Fig. 14 and in tabular form in Tables I to V. The first figure shows the relation between brinell hardness and heat treatment while the second and third shows the ultimate strength and the yield point versus heat treatment. There is nothing new or uncommon about these tests so they do not require much discussion. However, Fig. 11 shows the relation between the heat treatment and the fatigue strength and should be given close consideration. In these four figures the draw temperature is made the abscissa and the second variable is made the ordinate while the quenching temperatures form the isotherms shown. When the data is plotted in this manner the effect of the draw temperature is most clearly shown.

It is seen from the 1300-degree Fahr. isotherm of Fig. 11 that the drawing temperature does not affect fatigue strength when the quenching temperature is below the Ac_1 point. When the quenching temperature lies between Ac_1 and 1600 degrees Fahr., and the drawing temperature is below 500 degrees Fahr., it is seen that the steel does not offer great resistance to fatigue. This is probably due to the internal stresses set up by hardening and also to the inability of the material to undergo deformation. For the same range of quenching temperature, namely from Ac_1 to 1600 degrees Fahr., a drawing temperature between 600 and 700 degrees Fahr. gives the greatest fatigue strength but on further elevation of the drawing temperature the decrease in fatigue strength is very rapid.

It is seen that a different type of curve results when a quenching temperature of 1700 degrees Fahr. is reached. Two curves are shown for this quenching temperature, the one taking the form of a hyperbola as indicated by the smooth curve shown by the dotted line, the other is drawn so as to more nearly pass through each point as shown by the full line. One reason why it is thought that the 1700 degrees Fahr. curve might be a hyperbola is because one of the bars drawn at 450 degrees Fahr. withstood nearly 8,000,000 repetitions of stress before failure occurred. This is a good indication that the curve becomes parallel with the axis at low drawing temperatures. The bar showing such exceptionally high results was not included in the average for the 1700-degree quench and 450-degree draw heat treatment. When the 1700 degree Fahr. isotherm is drawn as shown by the full line, it somewhat resembles similar curves for some alloy steels and is thought to be the more accurate of the two. It may be that the change in the type of curve is due to the fact that on quenching from 1700 degrees Fahr. invisible hardening cracks are often produced. The fractures of the tensile test specimen quenched at 1700

degrees Fahr. frequently revealed that such hardening cracks were present.

If a large number of fine hardening cracks should transverse the specimen they would be instrumental in lowering the maximum fiber stress far below the calculated value and thus give a fictitious result for fatigue strength. To bring out more clearly the effect which the quenching temperature has on the yield point, ultimate and fatigue strength, data taken from the preceding curves were plotted with the quenching temperature as ordinate, the second variable as abscissa and the draw temperature forming the isotherms. The relation between these variables are shown in Figs. 12, 13, and 14. To avoid confusion, only the higher

TABLE I
CARBON SPRING STEEL QUENCHED AT 1300 DEGREES FAHR.

Temperature deg. Fahr.	Brinell Draw Hardness	No. of repetitions	Ultimate strength pounds per sq. inch	Yield point pounds per sq. inch	Elongation per cent	Reduction in area, per cent
None	269	.....	.....	.....	.....	.....
480	269	60,100	135,900	71,700	7.81	13.10
600	269	53,210	136,800	65,880	7.98	11.03
800	269	55,900	125,200	68,630	6.64	21.36
850	269	52,190	124,000	66,270	12.17	26.34
900	269	53,820	132,810	73,910	7.62	18.00
950	269	50,350	127,730	67,400	8.52	16.38
1000	269	56,960	136,680	73,180	8.14	13.75
1090	269	58,900	126,000	65,480	12.06	12.53

TABLE II
CARBON SPRING STEEL QUENCHED AT 1400 DEGREES FAHR.

Temperature deg. Fahr.	Brinell Draw Hardness	No. of repetitions	Ultimate strength pounds per sq. inch	Yield point pounds per sq. inch	Elongation per cent	Reduction in area, per cent
None	375	.....	.....	.....	.....	.....
440	364	104,800	158,460	111,300	0.72	3.00
600	364	110,900	152,430	112,000	1.15	4.35
800	364	102,540	155,700	118,080	0.78	6.68
855	360	88,480	158,100	117,900	2.73	18.07
920	351	106,910	155,000	111,850	1.88	6.50
950	351	67,420	155,200	111,410	1.23	14.43
1000	332	60,300	157,500	106,300	7.56	17.22
1050	311	79,925	150,900	100,610	9.95	20.25

TABLE III
CARBON SPRING STEEL QUENCHED AT 1500 DEGREES FAHR.

Temperature deg. Fahr.	Brinell Draw Hardness	No. of repetitions	Ultimate strength pounds per sq. inch	Yield point pounds per sq. inch	Elongation per cent	Reduction in area, per cent
None	444	.....	.....	.....	.....	.....
450	444	91,400	183,175	133,150	0.77	2.09
600	444	267,060	203,116	132,466	4.17	12.99
710	444	254,440	.....	.....	.....	.....
800	430	235,660	202,570	136,900	3.76	15.44
850	418	178,150	196,400	136,030	2.14	4.05
900	402	143,230	195,540	134,660	5.08	18.91
950	387	117,940	185,400	127,000	2.84	5.81
1000	375	110,160	178,800	123,000	3.19	5.30
1050	351	94,520	170,200	109,650	5.79	9.15

TABLE IV
CARBON SPRING STEEL QUENCHED AT 1600 DEGREES FAHR.

Temperature deg. Fahr.	Brinell Draw Hardness	No. of repetitions	Ultimate strength pounds per sq. inch	Yield point pounds per sq. inch	Elongation per cent	Reduction in area, per cent
None	477	....	....	....	....	....
450	512	49,200	....	137,920	0	0
600	495	172,400	217,517	151,980	2.1	4.8
800	477	141,530	229,066	153,615	8.4	3.8
850	460	102,200	224,600	153,700	8.9	3.9
900	444	97,596	210,766	155,280	4.2	10.4
950	418	77,366	192,860	143,200	5.98	3.0
1000	387	73,766	184,300	133,060	7.04	4.6
1050	375	62,733	173,800	125,880	9.8	5.1

TABLE V
CARBON SPRING STEEL QUENCHED AT 1700 DEGREES FAHR.*

Temperature deg. Fahr.	Brinell Draw Hardness	No. of repetitions	Ultimate strength pounds per sq. inch	Yield point pounds per sq. inch	Elongation per cent	Reduction in area, per cent
None	505	....	....	....	....	....
440	520	272,350 (2)	207,350	161,325	1.26	1.99 (2)
660	509	170,770	222,250	189,650	1.25	1.46 (2)
805	484	86,230	243,700	187,500	3.71	9.88 (1)
850	474	102,080	239,200	176,000	3.71	8.11 (1)
925	457	106,070	212,600	158,800	3.03	6.95 (2)
950	438	91,970	206,800	149,430	4.52	7.69
1000	418	85,216	189,130	133,370	4.81	9.47
1050	387	69,880	187,200	132,700	3.14	11.41 (1)

*About one-third of the specimens quenched at this temperature (1700 degrees Fahr.) showed a hardening crack when tested to destruction. To have some idea of the properties of this quench only specimens free from a hardening crack at point of fracture were included in the summary. The figures in parentheses is the number of tests in average if less than three. The third vibratory bar drawn at 440 degrees Fahr. required 7,962,140 repetitions for failure. Very small area of localization. This bar was omitted from average.

drawing temperatures are shown herewith and these are the temperatures almost invariably used in practice for heat treating parts subjected to repeated stresses. In plotting the curves of Fig. 14, it was assumed that the value of the fatigue strength remained constant for quenching temperatures below the A_{c1} point and that it was equal to that found for the 1300 degree Fahr. quench.

By inspection of this figure it is seen that the quenching temperature as well as the drawing temperature has a marked effect on the fatigue strength and that the maximum values are obtained at quenching temperatures of about 1460-1480 degrees Fahr. which is very close to the A_{cm} point of the material in question. It is therefore apparent that for the best fatigue resisting properties the quenching temperature must be just high enough to obliterate the previous existing grain structure. This takes place at the upper critical point, or in hypereutectoid steels at the temperature at which the free cementite is completely taken into solution. If time is allowed, the solution of the cementite will complete itself at temperatures lower than those shown but when the rate of heating is fairly rapid as it was in these experiments or as it ordinarily is in com-

mercial practice, then a temperature somewhat higher than the theoretical $A_{c\text{cm}}$ point must be used to compensate for the lack of time.

Attempts have been made in the past to connect the fatigue strength with the ultimate strength and the yield point but on comparing the curves of Fig. 14 with Figs. 12 and 13, it is seen that the fatigue strength cannot be a function of either of these two properties alone since the quenching temperature affects the ultimate strength and yield point in a manner entirely different from the fatigue strength. As the quenching temperature exceeds the A_{c1} point, the ultimate strength and yield point are seen to increase very rapidly and continue to increase, although at a slower rate at the higher quenching temperatures. On the other hand, the fatigue strength likewise increases rapidly after the quenching temperature passes the A_{c1} point but only continues to increase until the $A_{c\text{cm}}$ point is passed after which there is a sharp decline on further elevation of the quenching temperature.

The type of tensile test specimen used in these tests was that which the American Society for Testing Material recommends for flat steel. Within the gage length, the section is a rectangle of $10 \times \frac{1}{4}$ -inch dimen-

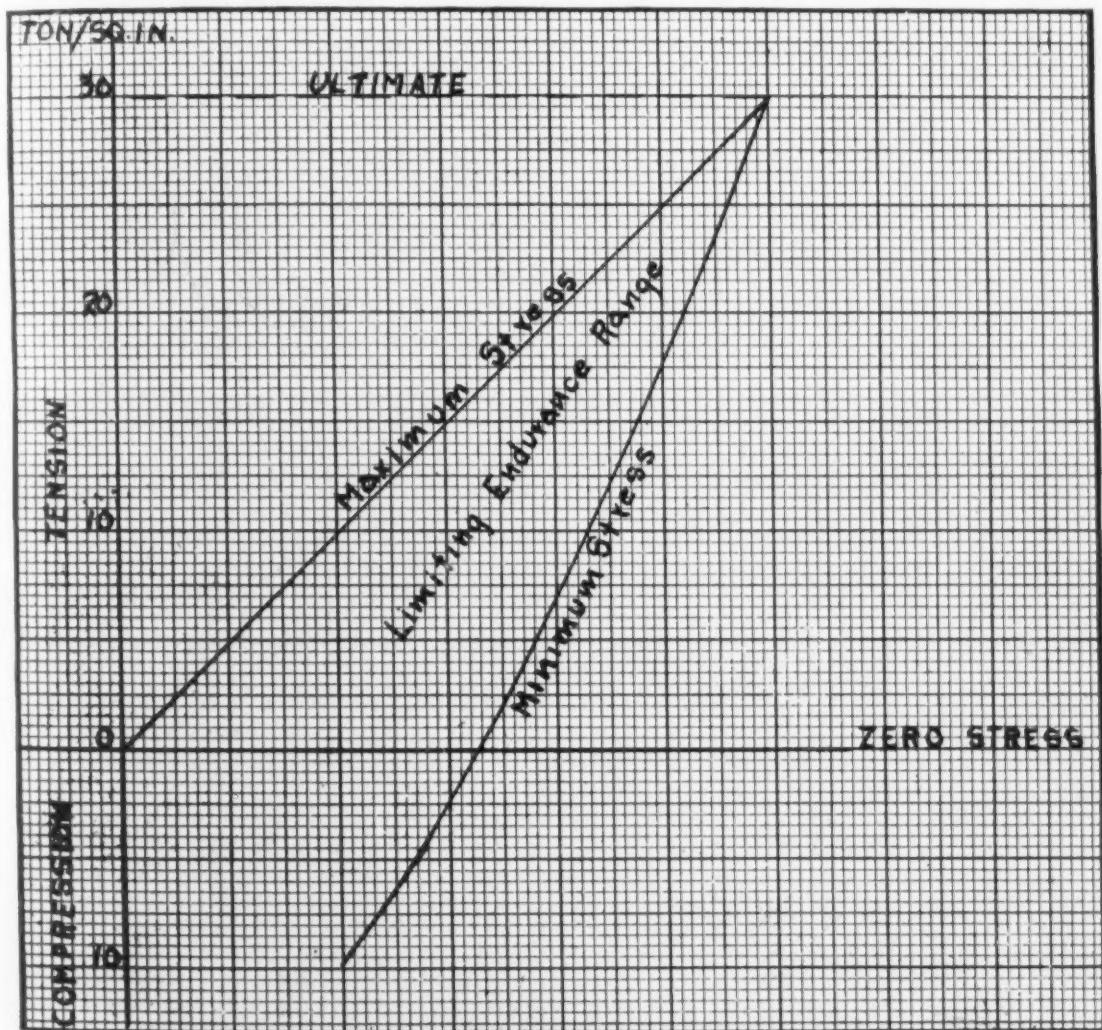


Fig. 6—Range of Stress at Which an Infinite Number of Repetitions Are Necessary to Produce Failure. (From Wohler's Results on Low Carbon Steel)

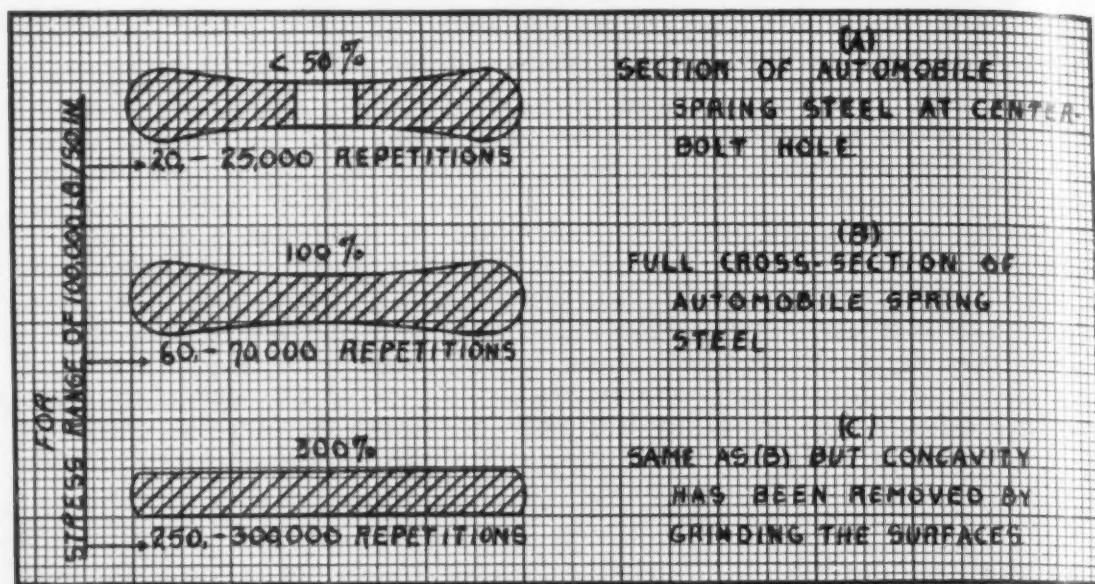


Fig. 7—The Effect of Shape on the Fatigue Strength

sions. This type of test specimen did not give consistent and concordant values for elongation and reduction of area and therefore no curves for these properties were plotted. However, judging from the results that have been obtained from tests made with the standard cylindrical test specimen it appears that these two properties when found in proper combination with the ultimate strength and yield point are fairly good indicators that the quenching temperature has been such as to confer maximum fatigue strength on the steel in question. Of course the heat treatment might be perfect and still the fatigue strength be low. Sometimes foreign inclusions greatly reduce the resistance to fatigue without ap-

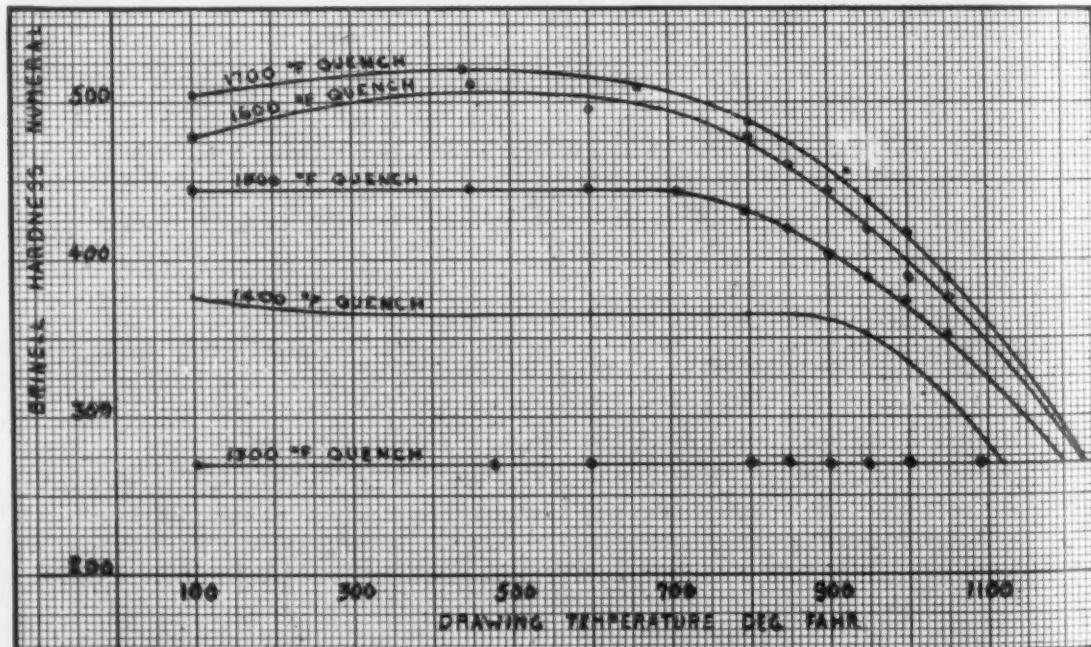


Fig. 8—Brinell Hardness with Relation to Heat Treatment of Carbon Spring Steel

preciable lowering the elongation and reduction of area. Thus it follows that although the physical properties as determined by the tensile test may be instrumental in indicating that heat treatment has been such as to develop the fatigue resisting properties to the fullest extent, still the whole story is not revealed without an actual test of fatigue strength. It is therefore to be regretted that better means have not been found whereby this property can be more quickly and accurately determined.

It will be of interest to compare our conclusions with those arrived

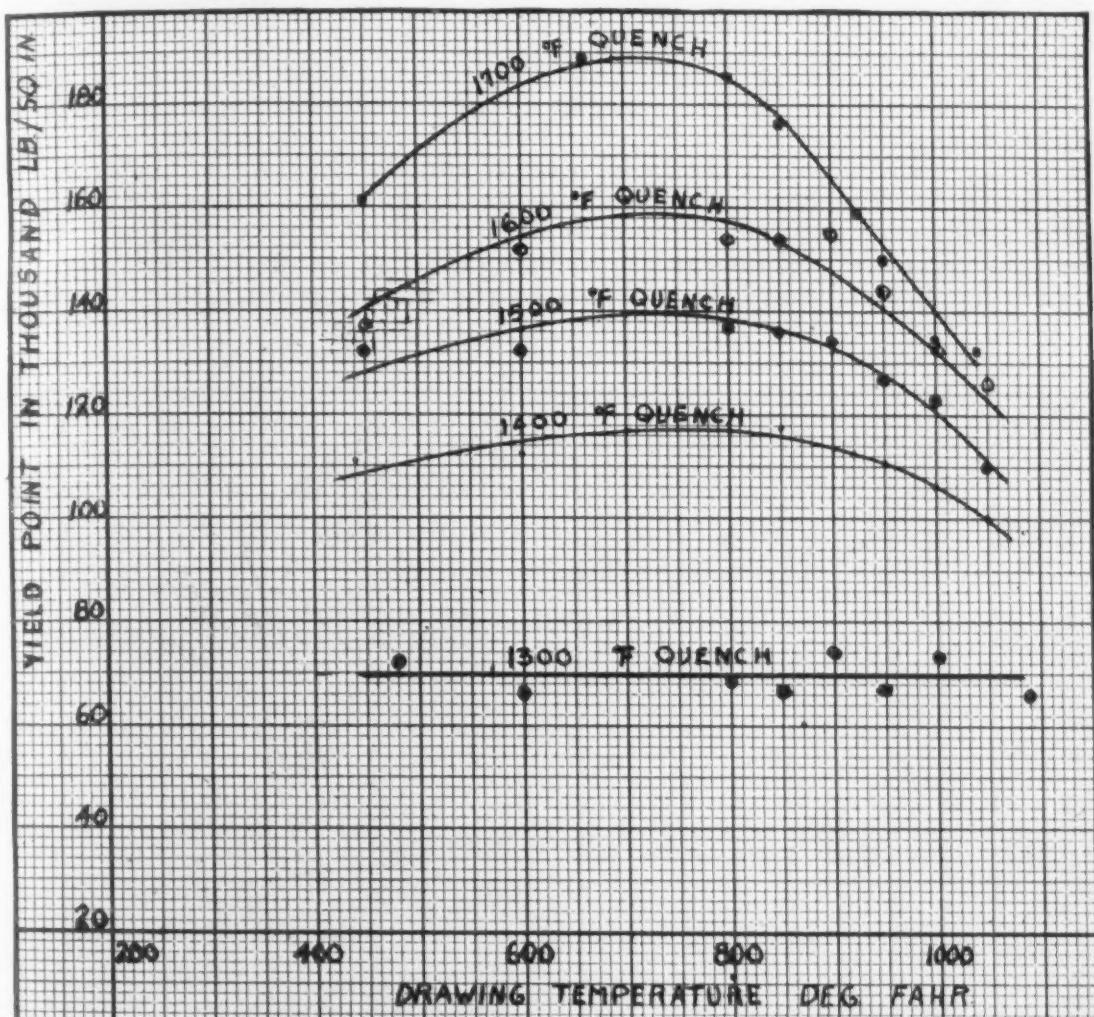


Fig. 9—Yield Point with Relation to Heat Treatment of Carbon Spring Steel

at in prior investigations dealing with the effect of heat treatment on the fatigue strength of steel. McAdams⁴ investigated the effect of the drawing temperature on chromium-nickel steel quenched at a constant temperature. His results show that as the draw temperature is lowered from 1300 degrees Fahr., the fatigue strength increases until a point somewhere between 1100 and 1000 degrees Fahr. is reached after which apparently the fatigue strength drops off. It is seen that these results are

⁴Proceedings American Society for Testing Materials, Vol. XVI, Part II, page 292, 1916.

somewhat similar to those obtained in our experiments dealing with carbon steel.

Gardner studied the relation existing between the microstructure and the limiting endurance range of stress. He found that specimens quenched at 850 degrees Cent. gave the maximum results, while a quenching temperature above or below this point caused the limiting range of stress to fall off rapidly. It was concluded by him that the larger the proportion of martensite the greater was the power to withstand repeated stresses. In an account of Gardner's work appearing in the Journal of Iron and Steel Inst. Vol. I, 1905, the kind of the steel used in his experiments is not stated.

Professor Kommers⁵ studied the effect of the quenching and drawing temperatures on the fatigue strength of three steels having a carbon content of 0.80, 1.06 and 1.30 per cent respectively. Although it is not pointed out in his conclusions, it can be seen on examining Fig. 5 that the quenching temperature, when followed by a draw temperature above 400 degrees Fahr. has a very marked effect on the resistance of steel to fatigue. Also that the quenching temperature giving maximum results, as in our own experiments, was found to be close to the upper critical point. It was

⁵American Machinist, page 551, April 1, 1915.

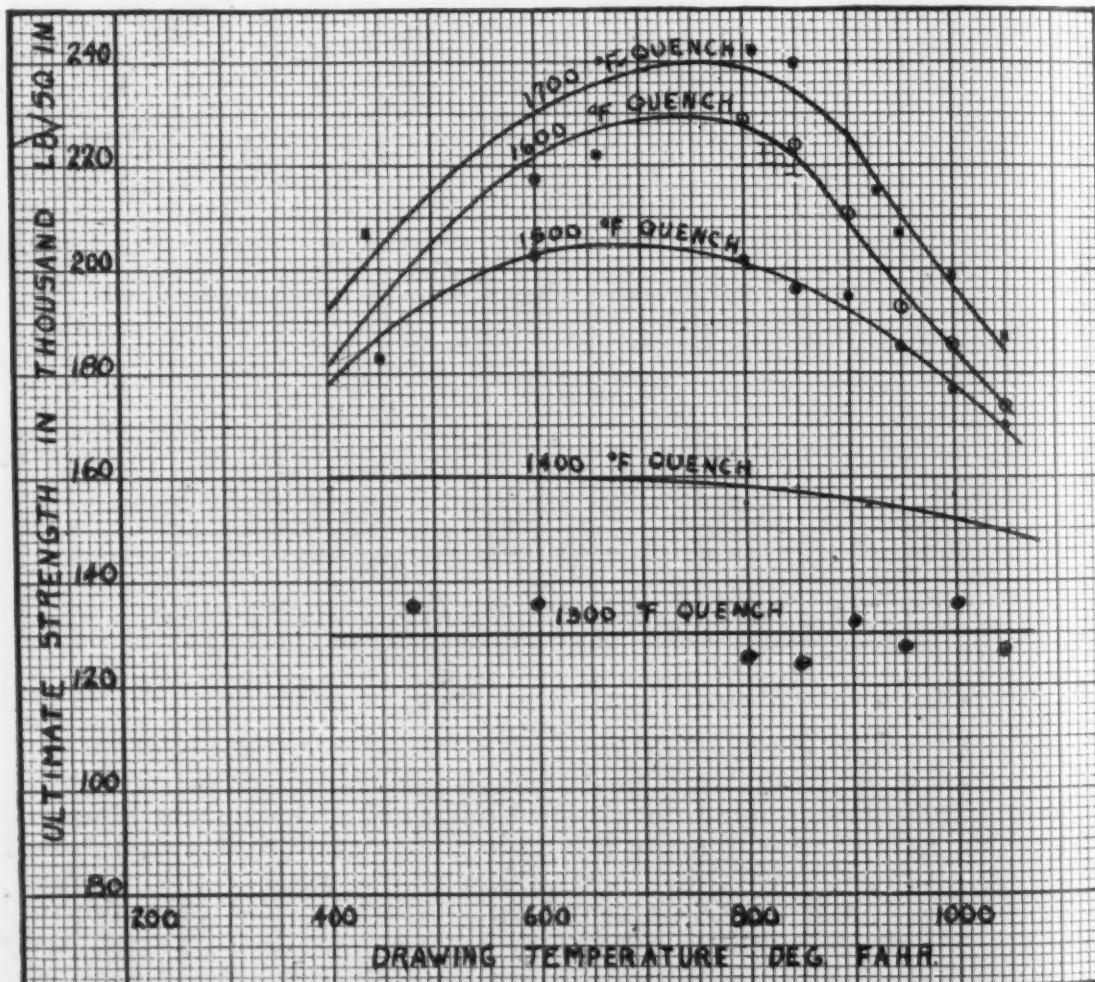


Fig. 10—Ultimate Strength with Relation to Heat Treatment of Carbon Spring Steel

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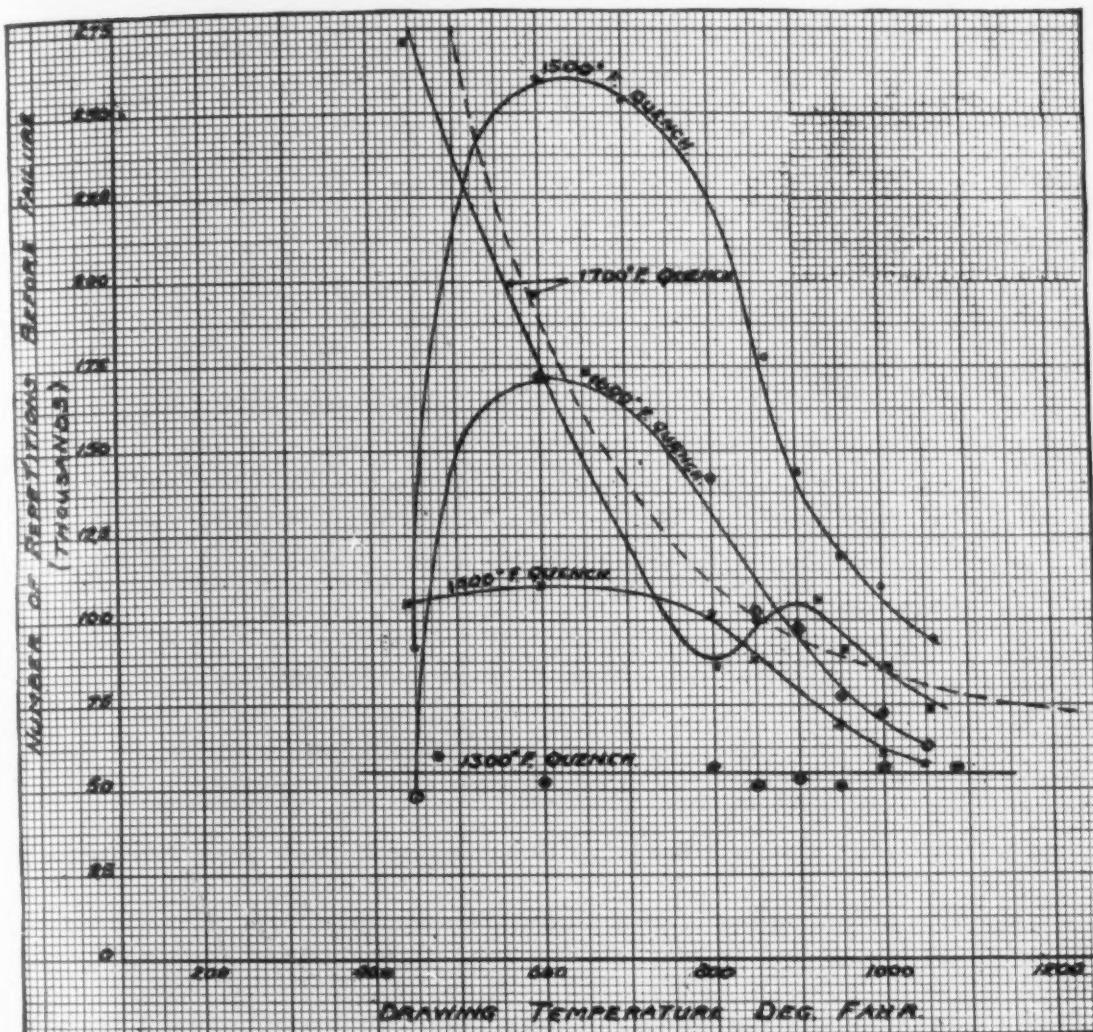


Fig. 11—Fatigue Strength with Relation to Heat Treatment of Carbon Spring Steel. Stress Range 0 to 150,000 Pounds per Square Inch

indeed pleasing to find these similarities existing between the two sets of experiments which were conducted independently and at such a wide variance of maximum fiber stress. The fiber stress in Kommer's experiments must have been very high as the number of repetitions for rupture seldom exceed two thousand. However, Kommer's experiments did not give conclusive results as to the effect of the drawing temperature. In some instances the drawing temperature gave a maximum result at temperatures near to those of Fig. 11, but in other cases the drawing temperature did not seem to have a very decided effect. Kommers concluded that a troostitic structure gives the best fatigue resisting properties. In the present experiments, the specimens having the highest fatigue strength on microscopic examination, likewise revealed a troostic structure.

Since for low values of stress the number of repetitions to produce failure approaches infinity, it follows that the influence of heat treatment in such cases is not so marked as in these experiments where the range of stress is high. In fact, Professor Moore concluded from his experiments⁶ that at low stresses nickel and chromium-nickel steel in the annealed condition give higher fatigue strength than specimens of the same steel in

⁶Proceedings American Society for Testing Materials, Vol. XIX, page 206, 1918.

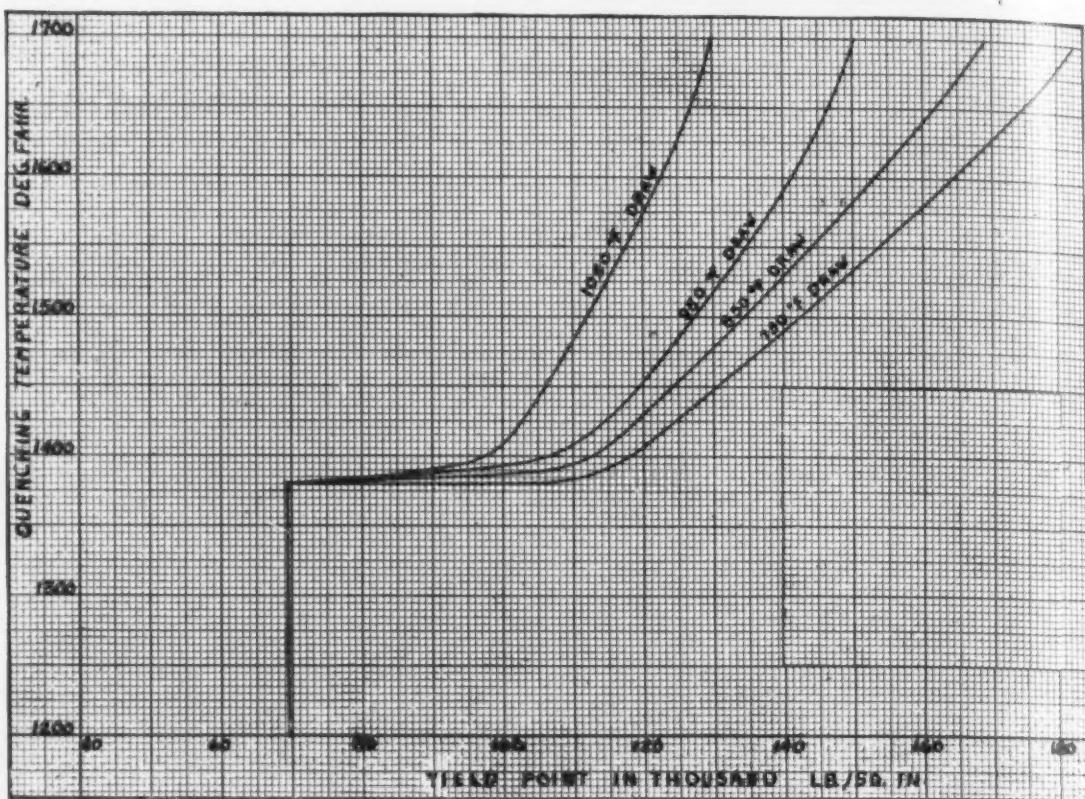


Fig. 12—Yield Point with Relation to Heat Treatment of Carbon Spring Steel

the heat treated condition. On the other hand, Abbot criticizes Professor Moore's statements and from the same experimental data concluded that the heat treated nickel steel shows a fatigue strength about triple that of the same steel in the annealed condition. It is therefore still doubtful as to what extent heat treatment influences the fatigue strength at low stress ranges.

The fact is the heat treater is not deeply concerned with low stress ranges since, as a general rule, only the most highly stressed parts are subjected to heat treatment. In the design of many parts it is often impossible to keep the stress within the limiting range. In such cases the heat treatment is depended upon to increase the number of repetitions which such parts will withstand before failure occurs. Therefore the effect of heat treatment on the fatigue strength at relatively high stresses is of more interest for practical purposes than is the effect which it exerts at stresses within the limiting range.

In the present experiments the range of stress was made equal to 150,000 pounds per square inch and is higher than the stress range ordinarily met in practice. Still the evidence accumulated through the examination of parts failing in service, indicates that heat treatment must have a decided effect on the fatigue strength at such stresses as are ordinarily met in automotive parts. Through the microscopic examination of various chassis parts, of different makes, material, and design which in service had failed through fatigue, it was found that in at least half of such cases the heat treatment had not been proper. Even under poorest conditions, the percentage of defective heat treatment in commercial practice does not

nearly approach so low a figure and therefore it can be concluded that heat treatment has a tremendous influence on the endurance of highly stressed parts.

Another fact met in practice and which is contrary to that expected is the effect which repetition of heat treatment has on steel that has already been subjected to repeated stresses. An example is an automobile leaf spring which has been in service for quite some time. It may become desirable to reshape such springs and this of course must be accompanied with, or followed by, a heat treating operation. If this heat treatment is such as is ordinarily used, it is found that failure will occur very shortly after being put back into service, in fact, in many instances failure occurs during the initial trip. Just why such a heat treatment after the parts have been in service should hasten failure is difficult to see, but that such is the fact cannot be evaded. Of course the secondary heat treatment again changes Bauschinger's "natural" elastic limits and perhaps the metal after once being subjected to oft-repeated stresses loses the power to again assume new "natural" elastic limits, or does so more slowly.

Problems such as these can best be solved by blending the thoughts and experience of the men in the field, the shop and the laboratory. This is what our Society has always attempted to do and it is one of the distinctive features which will make for its success. Our membership is not confined to either shop or technical men and since the views and experience of both are obtained, we should be best prepared to solve such problems as are before us.

Many heat treaters have not had the opportunity to become thoroughly familiar with the phenomenon of fatigue. All the subject matter of

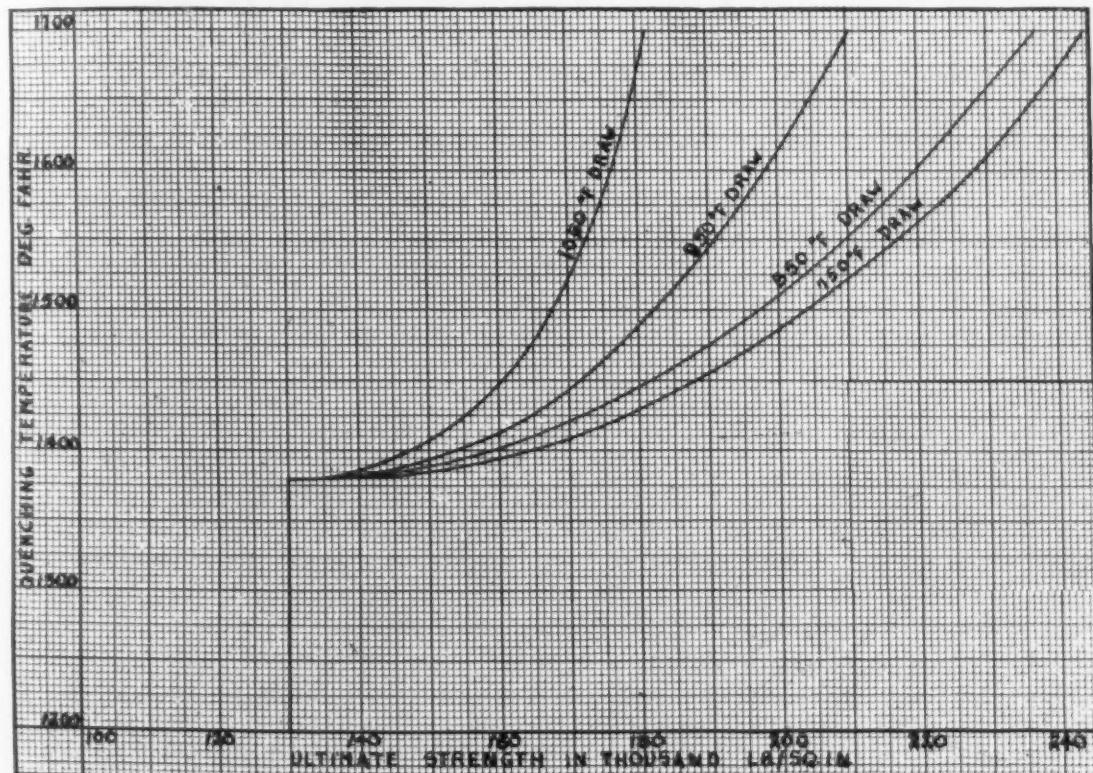


Fig. 13—Ultimate Strength with Relation to Heat Treatment of Carbon Spring Steel

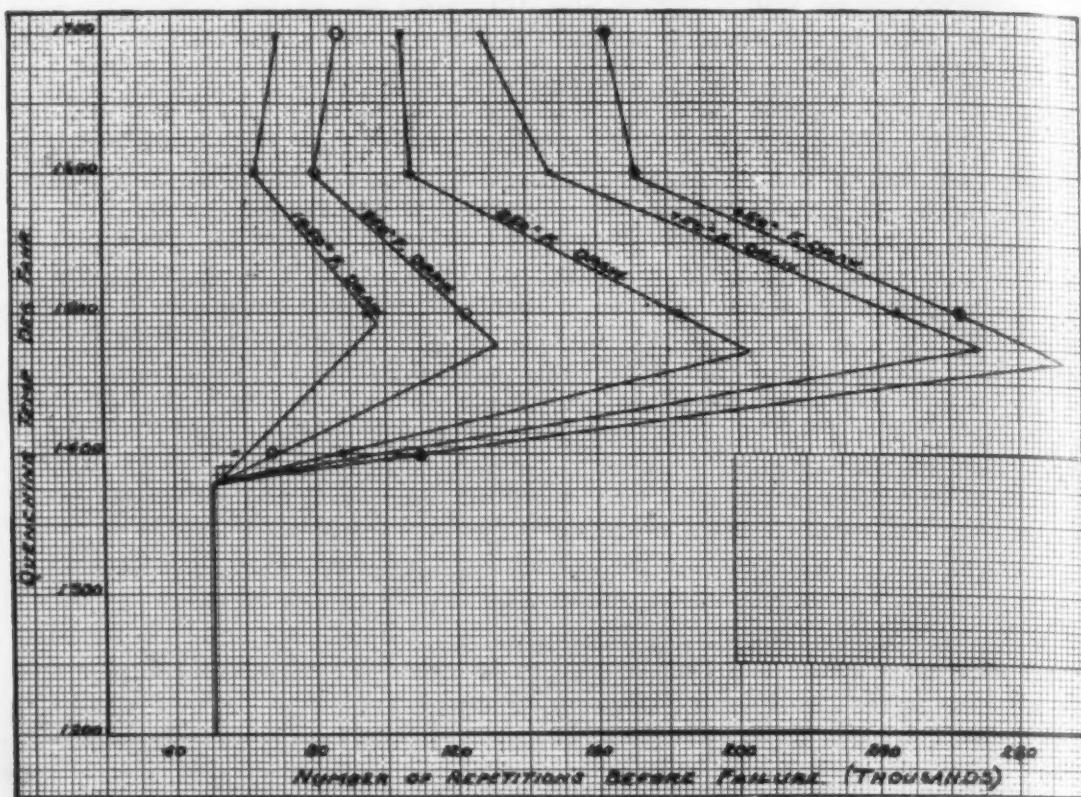


Fig. 14—Fatigue Strength with Relation to Heat Treatment of Carbon Spring Steel. Stress Range 0 to 150,000 Pounds per Square Inch

this necessarily highly compressed paper may not be so clear and explicit as desirable from the standpoint of the lay reader, however, if it is possible to convey to the heat treater, a certain few ideas regarding the effect of heat treating on fatigue strength it will be considered that the time necessary for the preparation of this paper has been well spent. The conclusions may be stated as follows:

1. That there is but one certain quenching temperature which yields maximum fatigue strength and that in the case of high carbon steel, this temperature corresponds closely to the A_{cm} point. It must be borne in mind that under shop conditions that A_{cm} point is somewhat higher than that generally given in text books because of the greater rapidity in heating.

2. Likewise the drawing temperature has a decided effect on the fatigue strength and there is one drawing temperature which yields maximum fatigue strength. After this maximum is reached, higher drawing temperatures bring about a rapid lowering of fatigue strength.

3. That experimental evidence strongly indicates that decarburization has a very detrimental effect on fatigue strength and therefore the heat treater should be careful to maintain a neutral or a nonoxidizing atmosphere while heating at the higher temperatures.

4. That duplication of the regular heat treatment will not cure fatigue but on the contrary will hasten failure of such parts that have already been subjected to repeated stresses.

It should be borne in mind that these conclusions hold for high carbon steel and do not necessarily apply to all alloy steels. It is hoped that further investigations will soon be completed which will reveal the rela-

tion existing between heat treatment and the fatigue strength of the alloy steels and since such data are desired by both the engineer and the heat treater, they should be forthcoming at an early date.

Discussion of Paper by E. P. and B. H. Stenger

MR. STENGER: The machine used in this series of experiments was an Olsen machine of the older type. In that machine the test specimen acts as a cantilever beam, that is, one end is clamped in the head of the machine, while the load is applied, at the other end, causing deflection in one direction only. Some of Wohler's early experiments were carried out with a machine which produced both tension and compression of uniform intensity throughout the entire cross section of the test specimen.

MEMBER: Is such a machine superior to the machine you speak of?

MR. STENGER: I do not think so. At least the later experimenters have found that the rotary machine gave much better results, that is, gave more consistent results.

MEMBER: Maximum fiber stresses in the case of a rotating specimen are confined to the surface, whereas in the tensile specimen the fiber stress is uniform. It seems as though the tensile machine would be the better.

MR. STENGER: It would seem so, but the tests made on the two types of machines show that one is about as good as the other as far as getting consistent results is concerned.

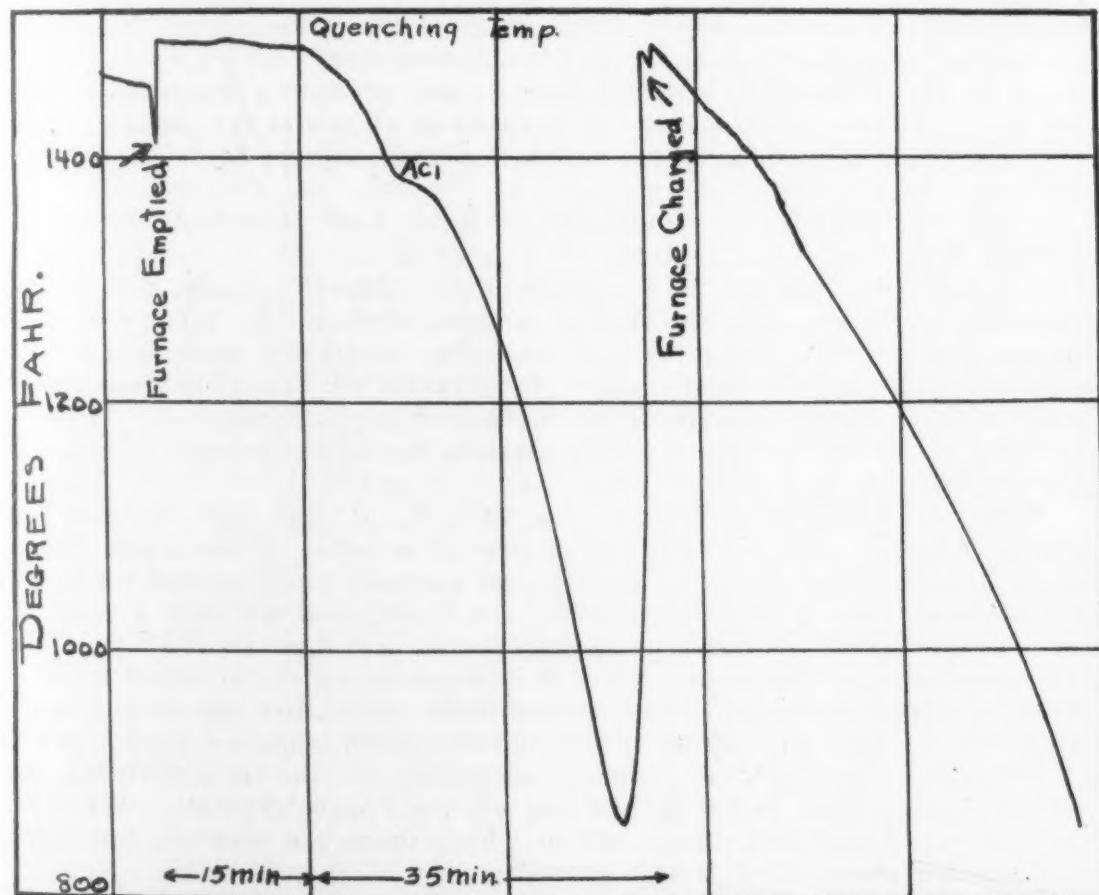


Fig. 15—Curve Which Shows Rate of Heating Specimens Tested

MEMBER: What was the speed of test of the stresses?

MR. STENGER: 550 applications per minute.

MEMBER: What is the reason higher speeds are not used to get quicker results?

MR. STENGER: Higher speeds could be used. There are no objections to using speeds up to 2000 reversals per minute. English experimenters have investigated this point and have concluded that as long as the reversals per minute are below 2000 the results are not affected by the speed. There is no reason why we could not have used a higher speed.

MEMBER: Is it an established fact that the speed has no influence on the result?

MR. STENGER: This has been worked out by careful experimenters and those are the conclusions they have reached, namely, that the speed, so long as it is below 2000 reversals per minute has no effect on the results.

MEMBER: How about higher speeds than that?

MR. STENGER: Higher speeds should give higher fatigue strength. Fatigue failure is the result of slip; amorphous material forms in the plane of the slip and it finally gives way. If the speed is above 2000 reversals per minute the load is applied for such a short time that the maximum effect is not produced at the point of highest stress.

MR. OLSEN: The question of laboratory tests is largely a question of what is to be tested. Where a rotary test might be good for some steels, in certain spring steels it gives no value at all. The test you had, of course, is a logical one for a spring steel.

DR. HARTZELL: I would like to ask regarding the fallacy that still exists as to crystallization. You spoke of slips and fatigue, etc. Can you tell us something about crystallization and why the so-called crystallization does not exist.

MR. STENGER: I would like to have your definition of crystallization first.

DR. HARTZELL: It is simply this: From a study of crystallography we know that the molten magma after solidification increases in size and crystal content, and we have in the steel a mass which was a molten magma. On solidification the crystals are set. Therefore there is no crystal growth after the solidification of the magma.

MR. STENGER: By crystallization is meant the growth of crystals or their increase in size.

DR. HARTZELL: That is true in a liquid, but that liquid is not a solid solution. That is true in course of mobility if the liquid has a slight line of demarcation, as we take an example such as water and oil and so on up into a solid solution like steel. In steel we have a solution but not the liquid. When it is molten we have a fluid mass as we ordinarily understand the term. That fluid mass being made up of a number of chemical compounds which chemically crystallize out as the mass begins to solidify, and before it completes solidification we have a mass of crystals. Crystals are growing according to the temperature; we run the temperature point up and we get the coarse crystals. We may have an iron-manganese compound in which there are crystals, but after solidification there is never any growth.

CHAIRMAN: I believe that is a thing that is pretty well established by former experimenters. Evidently what is a so-called crystalline

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break from fatigue is nothing more or less than a condition brought about by mechanical action of the break, whereas the actual microscopic crystalline arrangement remains exactly the same under the conditions after the fracture as it was before.

MR. LYNCH: A few months ago I had occasion to break a number of springs by fatigue methods, working them beyond the elastic limit, and thereby making a few hundred thousand vibrations. After breaking of these test samples, microscopical examinations were made, both near the fracture, within the stress zone, and just beyond the fracture, up in the clamp, where it was not stressed, and I found a decided growth in the microstructure, but in taking successive tests of that kind I found a very decided increase in the microscopic crystal formation or whatever you may call it. On account of the argument being on the other side, I wish to present this as a little experience I have had within the last two months, and it gives a good deal of indication to me there is a grain growth.

MR. STENGER: Mr. Lynch, what was the nature of the fracture? Did it show an area of fine grain material such as the fractures just shown or was it uniform throughout?

MR. LYNCH: The fractures were in every case what is known as a fatigue fracture, starting at the place of maximum stress on the outside of the rod. The tests were all taken on a bar stock. Of course there is a point of maximum stress, and all the fractures started at this point with a very small, fine grain structure at the outside, gradually going across and finally giving way with a fatigue breaking.

MR. STENGER: How would you explain this fine grain structure of which you speak? Have you found crystallization to occur at the same time in adjacent material or in material close by?

MR. LYNCH: When you start your fracture by a stress, you further localize the stresses and go still beyond the elastic limit at that point again until such time as it must fracture there. Regarding the question of grain growth, it did not happen at the fracture, but about $\frac{1}{4}$ inch from the fracture, and back in the zone that had been stressed hard before the fracture started. It was on account of this high stress, as I took it, that this grain growth had formed, but so far as at the fracture is concerned, I believe that is a localization of stresses, and the repeated increased localization of stresses until the fracture occurred after once being started.

MR. STENGER: Were your experiments carried out on heat treated material?

MR. LYNCH: Yes.

MEMBER: On carbon or alloy steels?

MR. LYNCH: On both.

MR. STENGER: You found the same to take place in both?

DR. HARTZELL: Was that determination macroscopic or microscopic? In other words, was your determination of the crystalline growth based upon a polished and etched section?

MR. LYNCH: Yes.

DR. HARTZELL: Then did you go on, below that to see whether the structure beneath, even a $1/64$ inch beneath that, was the same?

MR. LYNCH: I do not quite understand. We simply cut our sample in each case and took the microscopical photograph on the basis of 100 diameters, and we took one photograph only of each spring. We

tapped the surface of the spring all over and we took our photographs half way between the outside and the center in each case. We cut back of the fracture and cut directly across the bar.

DR. HARTZELL: How far from the actual zone of fracture?

MR. LYNCH: About a $\frac{1}{4}$ inch.

DR. HARTZELL: Then it would be $\frac{1}{4}$ inch one way and $\frac{1}{4}$ inch the other way.

MR. LYNCH: It was a peculiar kind of test where I was stressing a considerable portion of my spring.

DR. HARTZEZLL: Had you gone back beyond that you would have found that the original condition of the steel would have given you the same condition of the steel you found under the microscope.

MR. SHONTZ: Do I understand that the gentleman has stressed his steel above the elastic limit? The fatigue test does not usually refer to stresses that go above the elastic limit. Possibly he was getting a deformation there which, polished in a certain direction, made the grains appear to be larger at the point of fracture than they would be back where the steel is not stressed above the elastic limit.

MR. LYNCH: That brings up the question of what is the elastic limit. Some people call the yield point the elastic limit. Is the elastic limit when you pass the point of a straight line and get a curve, or when you reach that point? If you keep below that, of course, some tests can be made, and it is a question of whether you are going to break the specimen or not. If you are truly below your elastic limit our experience has been that little trouble with breakage will result. It is when you go beyond the elastic limit that breakage occurs. I am not speaking of the yield point.

MR. STENGER: You are speaking of the natural elastic limit as described by Bauschinger.

MR. LYNCH: Proportional limit or elastic limit: where they join each other.

CARBURIZING TEMPERATURES BEST SUITED FOR STEELS OF VARIOUS CARBON CONTENTS

By C. A. Haux*

(A Paper Prepared for the Philadelphia Convention)

Certain temperatures give best results for certain purposes. Too high temperatures mean outright failure or poor results at the best. High temperatures, besides producing poor work are expensive on account of the wear on the furnace and carburizing boxes. It is known that pots and boxes will stand up much longer at a temperature of 1650 degrees Fahr. than at 1800 degrees Fahr.

To find the proper temperature for a certain type of steel one must be governed by; 1, full analysis taken from several pieces of raw material to be carburized; and 2, by past experience. Depending upon memory for past experience would be poor policy; a good record will help wonderfully.

Requirements to obtain best results are dependable help. An honest inexperienced man is better than an experienced man that tries to cover up

* Foreman, Avery Co., Peoria, Ill.

mistakes so that his superior will not find out. A man of this type should not be tolerated within a heat treating plant.

Furnaces must be properly designed and in good working condition. Oil lines, if oil is used for fuel, should have double type strainers. These strainers should be cleaned not less than once every twenty-four hours to secure an even flow of oil. Pipes should be protected from cold or placed near to steam lines to prevent oil from becoming sluggish. Air blowers or turbines must be regulated to the proper pressure. Pyrometers should be used at all times, and a recording pyrometer should be so placed that the foreman can check the heat at any time during the run. Any shortcomings of the above means poor results or failure.

More failures are due to too high temperatures than any other causes. Failures also may be due to poor furnaces or defective pyrometers. In either case, they spell failure. On the other hand, if temperatures are too low, a poor product results from slow and shallow penetration of carbon.

Another item to be taken in consideration is: What are the carburized parts used for? A camshaft needs more careful handling than a piston pin. Are parts ground after heat treatment or are they used without finish? Are they required to stand up under strain, or is a wearing surface the only requirement? With these questions in mind, we proceed to figure proper carburizing temperatures.

The writer has found the following temperatures best suitable for carbon steel.

0.05 to 0.15 per cent carbon steel	1700 degrees Fahr.
0.15 to 0.25 per cent carbon steel	1675 degrees Fahr.
0.20 to 0.30 per cent carbon steel	1660 degrees Fahr.
0.30 to 0.40 per cent carbon steel	1650 degrees Fahr.
0.40 to 0.50 per cent carbon steel	1640 degrees Fahr.

Since these temperatures have been adopted they have been used with but very slight variation and where formerly higher temperatures caused trouble, the above mentioned have given excellent results.

Every heat treater will find a record sheet designed to include all heat treating operation from analyzing of steel to the final test a valuable help. These records will show each individual operation, giving operators name and number, furnace number, pattern number of parts, carburizing material used, and, in fact, a history of the whole proceedings to check back in case trouble should develop.

The record sheet from each indicating pyrometer together with analysis report should be placed on file with the heat treating record. Parts to be carburized can be stamped with a heat number and with the help of a good record can be traced back and further failures avoided.

This paper is not intended as a "cure all", neither does the author believe the temperatures given above are correct for all carbon steels. The analysis of steels should be taken in consideration in each case.

WHAT'S NEW IN METALLURGY

By E. E. Thum*

(Presented before Pittsburgh, Milwaukee and Chicago Chapters)

What's new in metallurgy? What's new in the science and art of producing metals and alloys of excellence from the minerals found in nature? What has happened in the past decade, the last year or two? What are the notable improvements just ahead, the trend of the next few years? What influence may the metallurgist be expected to have upon future civilization?

The word metallurgy images to many minds a small, dark, smoky, smelly, iron foundry, or to others a high board fence surrounding furnaces glaring with white heat, and powerful machinery superhuman in power and dexterity. But in its entirety, modern metallurgy influences our civilization down even to the commonest tools of life, and the initiated wonders to what state of savagery we would drop should it become a lost art.

The present has often been called the "age of steel". Our mode of life and material comforts are doubtless the result of a thousand factors, interlinked in a most amazing fashion, yet the influence of the metallurgical and mechanical engineer acting through the iron industry is certainly of great importance, as may be inferred from a brief retrospect of the last century:

One hundred years ago all American pig iron was made in small blast furnaces using charcoal as fuel and having a capacity of 25 to 30 tons per week. This impure, fusible metal was converted into wrought iron in sand-bottomed puddling furnaces of toy-like size, refining perhaps eight tons of metal per week. Hundred-pound lumps of this wrought iron were then taken white hot from the furnace, some impurities squeezed from the mass, and the spongy metal welded into a sound bar by rolling or hammering. Such bars were sold at \$100 per ton or more, and was the common metal used by blacksmith, machinist and builder.

Steel, which is essentially an alloy of carbon and iron, was made by the cementation process, packing the best wrought iron bars in charcoal, and heating the containers for days. Carbon was thus absorbed by the metal; the bars were then hammered into shapes for cutlery and other uses where a hard piece of iron was desired. This steel sold at about \$160 per ton, and in view of the value of a dollar in those years, could evidently be used only for most precious tools.

Huntsman, an Englishman, had found somewhat earlier that such cemented steel was more fusible than wrought iron and could be melted in a crucible, thus freeing it from undesirable slag inclusions always existing in the original bars. It was more recently discovered by metallurgists that scrap steel, wrought iron and carbon, if simply melted together in a crucible, would make steel; evidently a great measure of economy and a use for waste material. Indeed this is the more common method of making crucible steel at the present time. However, in 1910 crucible steel castings made of scrap steel and pig iron cost at least \$45 per ton, or if first quality cemented bar was used the cost was at least \$100 per ton. It can be seen that some radical improvement in the metallurgical and mechanical operations

* Associate editor, Chemical and Metallurgical Engineering, New York.

involved in steelmaking was necessary to reduce the price of steel to a point where it could be used extensively.

The years 1840 to 1850 were eventful to American iron metallurgy, witnessing particularly great improvements in the operation of blast furnaces — those tall shafts wherein a mixture of ore and white hot carbon react to form pig iron, and a waste slag containing most of the nonmetallic impurities. During this time the use of hot air for blast was introduced, coke or anthracite coal replaced the more expensive fuel charcoal, steam power was substituted for water power for forcing into the furnace the air required for combustion, the railways were beginning to develop, at once forming and widening a market for iron and steel products, tremendous beds of high grade hematite ore were discovered near Lake Superior, and the industry started to move toward Pittsburgh, where it would be more centrally located as far as its supplies of raw materials were concerned. All these factors combined to reduce the cost of pig iron, and with it the cost of wrought iron, so that in 1860 puddling costs in America had dropped to a point where rolled iron could be sold for \$60 per ton.

Meanwhile in 1856, Bessemer had made his invention of a pneumatic method for the production of steel, and after solving many metallurgical problems incidental to this revolutionary process, it was adopted rapidly. As already noted, wrought iron had hitherto been the material from which steel was made by carburization; wrought iron made by direct reduction of pure ores, or by purification of less pure cast iron in a small puddling furnace.

Bessemer discovered that if cold air were blown through a bath of molten pig iron, the impurities burned away rapidly, leaving the iron and a little carbon behind, and evolving sufficient heat to keep the resulting steel molten, despite its far higher melting point. A ton of liquid steel a minute, rather than a hundred-weight of pasty wrought iron an hour, was the result. Steel was made faster than pig iron could be found to make it from.

The specific influence of the Bessemer process upon prices may be judged from the quotation on steel rails in America. In 1868, before the process was widely used, the price was \$160 per ton, while in 1880, when it had been installed in many plants, the price had been reduced to \$70 per ton.

About 1880 occurred what was known as the Duquesne Revolution in the iron and steel industry in America, a term denoting the fact that a great many inventions in mechanics, improvements in metallurgy, and changes in the economic system conspired toward a tremendous increase in the efficiency of iron and steel making processes. Cheaply-won hematite ores from the Mesabi were beginning to be shipped down the great lakes. Blast furnaces were largely increased in height. Perfecting the hot-blast stove permitted an increased blast temperature, using combustible gases from the furnace top, formerly wasted. Many mechanical improvements were made in the automatic handling of ore at the mine; in loading and unloading on special ore boats; in its storage at the works; and in its selection and charging into the furnace top. Molten iron was taken directly from the blast furnace to the Bessemer converters. Soaking pits were introduced between the steel making department and the rolling mills, so that white-hot ingots of newly cast steel need not be cooled, but their original heat utilized in the working to shape. And finally tremendous improvements were made in the mechanical equipment of the mills for rolling a block-like ingot into a finished

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rail, structural shape, bar or plate. The combined effect of these advances may be judged from the fact that they lowered the price of steel rails from \$70 in 1880 to \$32 in 1890 and \$28 in 1910.

The influence on the price and production of pig iron is even more striking. In 1870, 2 million tons of pig iron were made at a cost of \$38. In 1880, 3 1-3 million tons were made at a selling price of \$26; in 1890 9 million tons at \$17 and in 1900, 14½ million tons at \$14. In 30 years, 7 times the tonnage at 1-3 the price. The capacity of blast furnaces in the 100 years under review had increased from 25 or 30 tons pig iron per week to as much an hour—200 fold.

Thus, whereas the main structural material a hundred years ago was hammered bar iron capable of sustaining 25,000 pounds per square inch before acquiring a permanent set, and selling at 4c or more per pound, structural steel having a yield point of 40,000 pounds per square inch, is now available in almost unlimited quantities. Consequently, in the intervening time metallurgists and mechanical engineers had offered civilization a huge amount of their most useful building material for 1½c per pound, which a hundred years ago was unattainable at any price and its nearest substitute would have cost in real money at least 6½c a pound for equivalent strength.

In view of this remarkable achievement, what yet remains to be done? Are we, as a blast furnace enthusiast recently put it, "approaching the uniformity of perfection?" Certainly the rate of progress in recent years is marvelous as compared to the lingering two thousand years which elapsed between the invention of the first crude bellows, and its equipment with a simple flap valve. At the present speed, we cannot stop short without wrecking civilization.

The author ventures to say that the developments of the next few years will be an extension of the progress of the last century; that is in getting the most strength for the least money or in the least weight of metal. You recollect that we now use steels instead of weaker wrought iron. That advantage must be pressed. Motor traffic and aviation have demonstrated that lightness in moving parts is no less essential than strength. That great and almost universal disregard of weight instanced in railway rolling stock soon will be a thing of the past, as it becomes increasingly apparent to even the most conservative manager that it takes tons of expensive coal to haul dead weight back and forth across the country to no effect except to wear out good roadbeds.

The easiest rivers have been spanned. The utmost resources of bridge designers have been stopped short at a point where the bridge can safely carry nothing more than its own weight. Yet if only the tension members in a bridge of mild steel could be replaced with another slightly stronger and dependable steel having a yield point of 50,000 pounds per square inch, the limiting cantilever span would be increased from 2000 to 2350 feet.

One naturally expects that alloy steels will fill this need. Past centuries have brought us from the analloyed iron known as wrought iron to steel, pure iron alloyed with carbon. The near future will add a commanding percentage of other metals to this simple alloy. And here the resources of the modern metallurgist are almost limitless and the possibilities almost untouched, even though from an insignificant production in 1910, 7 1-3 million tons of alloy steels were melted in the last 5 years. True, we have known about nickel steels and steels containing high manganese for many years.

More complex alloys have been utilized for armor and armor-piercing projectiles. Some essential properties of tungsten steels have been known for over 50 years—they possess the remarkable property of intense hardness even after slow cooling. Such self-hardening steels were discovered by Robert Mushet between 1860 and 1870, and metalworking tools made from them. Not until the Paris Exposition of 1900, however, did the modern era in tool steel begin; then the American, Frederick W. Taylor, first exhibited the spectacle of a tool cutting so rapidly and deep that it delivered chips of metal at a blue heat and in amazing quantities. Since that time the introduction of modern scientific shop management has been going on apace, wholly made possible by the use of these high speed tools, of steel alloyed with tungsten and chromium, cutting four times as much metal as the best of the older high carbon steels.

Alloy steels containing nickel are notoriously hard to make, and are subject to that mysterious defect called "flakes"—almost unknown in this country until during the war when we needed great tonnages of it for gun tubes, recoil cylinders and breech housings. "Flakes" appear as bright silvery areas in the broken ends of test-bars, which would otherwise possess a mossy or closely granular fracture. Flakes seem not to affect the strength of the metal, but diminish its ductility almost to zero. Their cause was so obscure and their cure so difficult that one of the most prominent and highly respected of American metallurgists, publicly stated that the way to make nickel steel successfully was to leave out the nickel!

Yet Federico Giolitti, an eminent Italian metallurgist, has utilized these same medium-hard nickel steels for the production of heat treated steel castings of such high quality that they replaced forgings on hundreds of field gun mounts made by the Ansaldo Co. for the Allied governments. Bear in mind that castings ordinarily represent the poorest quality in metallic goods, while forgings usually call to mind the most excellent materials. With this difficult alloy, the Italians make castings entirely free of that brittleness and weakness nearly always found in forged, pressed or rolled steels when tested transversely. Castings which withstood the ultimate test with entire satisfaction—the battering of exhausting service in the Great War. Castings lighter than forgings, but equally strong; castings made much more cheaply, rapidly, and with less machine work than the parts they replaced.

Heat treatment has a great share in developing the superior qualities of alloys. The ancient smith who pushed his crude forging into a puddle of water so it could be handled the more quickly, was the first heat treater. Modern industry demands much more precise control of this most important manufacturing step.

With all the resources of the periodic table of chemical elements available for alloying and the infinite combinations of times and temperatures for heating and speeds for cooling, search for new and better mixtures or improvements in old would seem almost as hopeless. Progress would come only by accident and enshrouded with secret practices and worthless nostrums. Fortunately we have another new thing to aid us which has set agog the whole art of getting metals: A systematic study of the physics and chemistry of alloys as influenced by composition and heat treatment, the lusty young science of metallography. Sorby, Martens, Tscherenoff, and Brinell were the pioneers in the use of the microscope in the study of metals, but the Frenchman, Osmond, as late as 1888 supplied the key to many metallurgical mysteries by postulating the allotropy of iron—the idea

that the internal configuration of the iron molecule suffers profound changes, called allotropic modifications, at no less than two different temperature regions. In passing one might remark that iron is by no means the only metal which masquerades in various guises.

It is hardly necessary to offer arguments concerning the importance of the metallographic method to science. Its remarkable growth and widespread use in the shop is sufficient and ample evidence of its value to industry. From a relatively unimportant branch of physical chemistry it has been developed into a means of investigating the properties of metals and alloys on a par with the older methods of chemical and mechanical testing and very frequently solves problems which are inexplicable by the older methods alone.

Physical properties such as hardness, strength, toughness, or magnetism are much more closely related to the minute structure of the material than they are to the percentages of the various elements comprising the alloy. Today no one questions the value of chemical analysis in metallurgical work, but a microscopic examination may be and often has been of far greater value in explaining the properties and predicting the uses of the finished product. The way the various elements combine into chemical compounds, their reactions with each other, the physical properties of the various microconstituents comprising the alloy, their relative size and distribution, the occurrence of impurities, extraneous substances, or "inclusions", and the structural effects of thermal and mechanical treatment are factors we now know to be of supreme importance in determining the properties of the material.

It is in the metallurgy of iron and steel that the metallographic method has found widest application, a natural consequence of the great industrial importance of steel and of the complex nature of the alloy itself. Here iron is extremely magnetic, there almost nonmagnetic; in one form it is brittle as glass; in another almost as ductile and soft as copper; here it is most resili-ent, there it lies almost as springless and dead as lead; now it is somewhat fusible, then very infusible; here it welds readily, there it can hardly be welded at all; in our files and razors it is extremely hard, in our horseshoe nails it is so soft that the farrier rejects them unless he can bend them on his forehead.

However, there have been found to occur at times profound changes in the strength or hardness, or magnetism of a metal, even solid metal, without any corresponding change in the chemical composition, or indeed any visible change, powerful though the microscope may be. Yet the metal is undoubtedly a different metal; some change in structure must have occurred.

The newest thing in metallography is the study of these ultramicroscopic and even subatomic changes. Difficult though it may be to interpret the realities of things so small as to be utterly beyond our unaided senses of touch and sight, the metallurgist is now facing the still more difficult task of comprehending particles smaller than the wave of light, smaller than the X-ray, even approaching infinite minuteness.

In the complete analysis of metallic structure he is concerned with the ultimate particles of matter—the electron, atom and molecule. It is not sufficient for him merely to recognize that such particles exist and that the atom is an extremely small particle of matter which is the unit of chemical combination. He must ultimately gain some appreciation of the actual sizes of these particles, of their properties, and especially of their relations and

the forces existing between one another. In this way a mental picture can be formed of the construction of metals, and of the mechanism of certain changes in structure which profoundly affect their physical properties and their utility. When this view-point is finally reached, great advances in metallurgy can be directed easily.

How difficult is this feat may be realized when one tries to imagine even the size of such small particles as atoms. Tungsten, for example, which has a specific gravity of slightly over 19, requires about 100 million atoms, as they are normally spaced at room temperature, to make a linear inch. Let us attempt to realize what a 100 millionth of an inch, the diameter of an atom's sphere, is like.

We are in the habit of visualizing all objects in terms of things which we can see with the unaided eye—for instance, we make a map of as large an area as the continent of North America and reduce it to such an extent that we can see its general geographical characteristics on one page or one map. On the other hand, we magnify very small objects to such an extent that we can see their photograph or other physical likeness. Atoms are so minute that it is almost impossible to select a magnification by which this can be done, but let us suppose that we replace atoms by spheres one-hundredths of an inch in diameter—about the size of a particle of pulverized sugar—and let us further suppose that we put as many of these tiny spheres in a row as there would be tungsten atoms in an inch. The row would be 15 miles long! Translating this into volumes is much more difficult, for 3400 cubic miles is something we cannot handle. But if each atom in a cubic inch of tungsten were changed into a grain of pulverized sugar, we could fill Lake Superior with it, or supply a second Niagara for 75 years!

Yet these infinitesimal things, which may be after all nothing more than 99.99 per cent space, and the balance points where the all pervading ether is strained a bit, arrange themselves for the most part in perfect orderly, geometrical fashion when changing from liquid to solid. That much had been inferred from microscopic examination of large assemblages of atoms; it has lately been proved by X-rays reflected by the individual atoms.

Fraunhofer made a so-called diffraction grating by ruling finest scratches on glass, several hundred to the inch. A beam of light falling obliquely on this ruled surface develops beautiful spectral bands of rainbow colors due to the fact that the wave reflected from each succeeding ruling is slightly out of step with its predecessor and causes certain well understood interference effects. When enough of these steps add together to make half a wave length, complete interference and light extinction results. Pure yellow light, for instance, would be reflected as a series of yellow bands of shaded intensities, separated by dark strips, whose spacing, center to center, is a function of the wave length of the light and the closeness of the ruling.

Now if crystals are actually composed of atoms set in regular rows and ranks, it would doubtless act as a diffraction grating, to the right kind of wave motion. True, such rulings are inconceivably fine, but we have available the X-ray for their analysis, and X-rays are 20 thousand times as short as light waves. Following these considerations, it has actually been found that a beam of these waves of known length, reflected from a crystal or mineral to a photographic plate, will develop figures from which not only the distance center to center of atoms may be figured, but their

location in the so-called space-lattice determined as well. The actual structure of a crystal can thus be diagrammed; most metals so far studied have a space lattice similar to a series of cubes, regularly placed, side by side and top and bottom; atoms are located at the corners of these imaginary cubes, and the crystalline system is called cubic. If, as is often the case, there is an additional atom at the center of each face, the cubes are said to be face-centered; if in the geometric center of the cube, body-centered. Investigations of atomic structure have not progressed far enough to furnish many generalizations, but it seems clear that eventually we will arrive at fundamental principles of the utmost usefulness.

We are fairly sure, for instance, that at ordinary temperatures mild steel consists of crystals of pure alpha iron and crystals not of carbon but of a chemical compound between iron and carbon which has been named cementite. Now if this steel is heated to about 900 degrees Cent., the alpha iron changes into another allotropic modification called gamma iron, and the carbide cementite appears to diffuse itself uniformly through the iron—it actually goes into solution, even though the metal is far from its melting point. The resulting solid solution has been called austenite.

Now it is a matter of considerable importance that the mechanism of this action be clearly understood. Carbon may be absorbed by iron in many ways and from many sources—are all the resulting steels alike? Does cementite enter solid solution as a compound and retain its individuality at all times; or does it dissociate into its elements iron and carbon at this relatively low temperature of transformation? X-ray analysis has come to our aid by showing that molecules or compounds do not exist as such in crystalline solids; the unit of organization is the individual atom. For the case in point this amounts to saying that carbon assumes the same position in the austenitic space lattice whether it has been absorbed from graphite, cementite or any carbonaceous compound, and each atom of carbon is held in that position by balanced forces from an unknown but very large number of surrounding particles, both of iron and carbon, and not by the three iron atoms which bind it fast in the compound cementite.

Despite the extraordinary "directional" nature of forces acting between atoms, a force so strong that it is impossible to quench a liquid metal rapidly enough to prevent it solidifying as an aggregate of minute crystalline grains, it is clear that at surfaces separating one crystal from another are located many atoms which are under great stress from crystals on either side, and which do not exactly conform in orientation to any of the atoms about them, and are therefore without crystalline form, literally "amorphous". But this is not the only locus of amorphous metal. We also know that allotropic metals recrystallize when they pass from high temperatures where one phase is stable to a lower, more agreeable to a second modification. Amorphous material apparently cements the smaller and what might be called "secondary" grains of such recrystallized metal. A third occurrence of amorphous metal is found in ductile metals, strained beyond the elastic limit. The so-called permanent set is a result of movements within the crystal itself; the crystals break into blocks, which slide past each other along cleavage planes to new positions of stability, the movement apparently disorganizing several layers of atoms along the slips, producing much non-crystalline or amorphous metal on those planes.

A consideration of the properties of different pure metals, containing various proportions of crystalline and amorphous phases, has established the

conclusion that each phase has a definite and peculiar set of properties. Thus, crystalline matter is relatively soft, ductile and weak, while the same kind of atoms when existing in the amorphous state build up an aggregate which is relatively hard, brittle and strong. Moreover, a crystal will sustain a considerable load in a truly elastic manner—the atoms are pulled slightly further apart, or pushed slightly closer together, but through it all they retain their general configuration and return to the original spacing on release of the load. Heavier loads, less than the ultimate strength, merely cause slip along the cleavage planes—as noted above permanent set ensues, but even yet the load will be supported indefinitely.

I need not dwell upon the importance of these conclusions, so recently formulated as to be among the new things in metallurgy. Extreme fineness in crystalline grain, if it does nothing else, increases the relative amount of amorphous metal in the piece, and imparts a larger share of the special properties of this phase; that is, strength, hardness and brittleness. Although he may not have known the reason for his practice, the smith from time immemorial has endeavored to keep the crystals in his metal as small as possible, by alternate heating, cooling, forging and annealing. Successful heat treatment even today consists in procuring the maximum of the desirable strength with the minimum of the undesirable brittleness, both inherent properties of amorphous steel.

Reverting from this digression to our thoughts on the constitution of that complex substance called metal—a study which is among the newest things in metallurgy—it may be remarked that the phenomenon of hardening still lacks a complete explanation. Why is it that pure iron or copper cannot be usefully hardened, that high carbon steel is glass hard after quenching and soft after slow cooling; that manganese steel is just the opposite—relatively soft after quenching and hard after slow cooling; that duralumin is soft after quenching but becomes progressively harder on resting at room temperature?

There is no time for a critical review of the enormous amount of precise scientific work which has been done on this problem during the last 30 years, nor to examine the various hypotheses which have been advanced. The newest hypothesis, a brilliant conception proposed independently by Jerome Alexander and Zay Jeffries, explains many more of the hitherto unexplainable facts than its predecessors. It may be dubbed the "critical dispersion" theory, and postulates that when a metal or alloy acquires relatively great hardness, it is due to the presence of a second substance dispersed in the original crystals in what might be called a critical size and distribution. This dispersed material may be a pure metal or a compound, but it must be harder than the metal from whence it was born. The particles must be scattered very closely throughout the crystal, and act by interfering with that normal property, the ability to deform by the development of a few large slips, in three ways: first, they prevent the initiation of slip between crystalline layers as would billions of tiny staples in the leaves of a book; next, the slips once started despite this hindrance do not get very far because of the internal friction against the little anchors; and third, the number of slip planes produced by incipient plastic flow, and therefore the absolute amount of hard resisting amorphous material is greatly increased.

Thus the presence of these tiny particles, possibly crystals containing only a few atoms and therefore of ultramicroscopic or colloidal size, hardens and strengthens the metallic grains containing them by increasing the inherent

capacity of a crystal for resisting change under the presence of external force.

Brief mention of the way the theory fits into commonly observed facts in the hardening of high carbon steel will be interesting. At high temperatures the carbon is in solid solution gamma iron—that is, dispersed as atoms. Most drastic quenching prevents any but incipient precipitation, and so maintains an unstable condition little different from the original austenite. The quenched metal is relatively soft.

On quite slow cooling the carbide cementite not only has time to form and precipitate from a large mass of soft ductile alpha iron, but to agglomerate into sizable crystals and plates, appearing under the microscope as "pearlite", well known to metallographers. Notwithstanding the fact that cementite is of itself quite hard, it has accumulated into large crystals which are quite brittle and they themselves crack before presenting effective resistance to crystalline slip in the pure iron matrix under applied stress. The slowly cooled metal is also soft. Therefore, we have extremes in quenching rate, producing extremes in the dispersion of the insoluble constituent, but there is comparatively little difference in the resulting hardness, strength or toughness.

If the quenching is not quite so drastic, however, or if the austenitic metal be given a very gentle anneal—as boiling in water—time and atomic mobility will enable the insoluble and highly dispersed atoms of carbide to accumulate into somewhat larger particles, and strangely enough, maximum hardness ensues. Under the microscope, no separate particles are yet visible; the resulting structure, which has been called martensite, has the regular etch markings characteristic of pure metal or solid solution. The accumulated cementite cannot be seen, yet it offers maximum resistance to crystalline distortion in the surrounding metal.

Further decrease in quenching velocity will allow further accumulation of cementite particles; under the microscope they are still invisible. The appearance after etching is changed and apparently structureless; it has been named troostite. Hardness is reduced somewhat, but the tensile strength is now a maximum. Still slower cooling produces a cloudy structure called sorbite, the accumulation of cementite, though still ultramicroscopic, is then correct for maximum toughness. Here are three well defined stages between the extremes, and one can hardly imagine a more perfect series of phenomena for proving the dependence of physical properties upon degree of dispersion. It is probably true that it has not been proposed before because it is all so simple.

In fact, colloid chemistry, the chemistry and physics of ultramicroscopic particles containing only a few molecules, is a tool whose application to metallurgy is a future step which may confidently be expected to bear rich fruit. Especially will this aid in understanding the diffusion of gases into and through hot or cold metals, weakening the bond between crystals and sometimes causing disastrous and most mysterious explosions; the action of certain alloying elements, such as silicon or titanium, which clear a molten bath of a quantity of gas or slag wholly disproportional to the actual amount added; or again, the great influence which a small amount of other metals has upon the grain size of a casting. If any one yet doubts the practical utility of such submicroscopic investigations, he may be reassured to know that considerations as to colloidal dispersions and intra-atomic forces have pointed the way to quite recent but fundamental improvements in the aluminum industry.

For possible and future uses of what might be suspected of being pure science, it may be pointed out that another way of getting the maximum of strength with the minimum of weight is in super-refining our common alloys, an endeavor which has received all too little attention in recent years. No one yet knows why pig iron from the small cold-blast charcoal furnace makes stronger castings than that from the towering monsters in use today. Again, mild steel with an elastic limit of 45,000 pounds per square inch has had its strength increased 20 per cent after electric refining. The analysis is substantially unchanged, and no difference can be detected in the structure. I venture the prediction that when such riddles are solved, as solved they must be, they will be found to depend upon particles and forces too minute for determination in a test tube, microscope or tension machine.

In ancient years of course only the very purest and richest of ores were used; deposits which might be called bonanzas having been worked up to the present time. Very important deposits are mined in Great Britain containing 90 per cent of ferrous oxide and the balance nearly all moisture, an ore which is naturally very easy to smelt. However the most important British ore in point of tonnage at the present time is the so-called Cleveland ironstone, a ferrous carbonate containing only 33 per cent iron, and high in phosphorus.

The sulphur problem is probably the most important one which must be solved by the iron metallurgist in the near future. Low-sulphur ore and low-sulphur fuel is rapidly becoming exhausted; some sulphur can be eliminated in the blast furnace by running a very basic slag, high in lime, but once sulphur gets in the pig iron it stays there most tenaciously; in fact increased in quantity with each remelting. The basic steel process has eliminated phosphorus, that other enemy of ductile iron, but sulphur control is uncertain at best, and expensive electric furnace refining is now the refuge of the most progressive steel plants and iron founders insisting upon quality metal.

France and Germany also depend almost exclusively upon quite lean ores. The bulk of their iron tonnage is produced from the so-called Minette ore of Lorraine, containing from 27 to 37 per cent iron and up to 2 per cent phosphorus. Some of these ores are high in silica, others high in lime; a mixture can easily be made which can be smelted with little or no additions of material containing no iron, evidently a powerful factor toward making so low grade an ore commercial today.

America is extremely fortunate in having wonderful deposits at the Lake Superior region, from which millions upon millions of tons have been shipped averaging slightly over 61 per cent iron. These ores are low in impurities; while not self fluxing, the amount of waste material is not so large but that the ore is extremely desirable in view of the cheap mining cost. The end of these deposits, however is only a question of time. When that time will be no one is safe in saying, since new developments have so far been able to replace the amount of ore which is carried down the lakes in steamers.

A problem for the future to solve is the utilization of less pure ores now known to exist in the region in huge quantities. In fact that will be the problem before the whole iron trade, no matter where it is situated, in but a comparatively few years. Vast stores of hematites exist in the Lake region, either containing so much moisture or so much clayey earth that they may not be profitably smelted as they are. Already simple drying and washing plants are in operation on these ores. The greater perfection of

these processes and wide adoption will extend the life of the lake ranges many times its present expectancy, great though it may be.

Another move in the right direction is being made in the erection of a plant on the end of the Mesabi range, having a capacity of 3000 tons per day, to concentrate the so-called taconite which exists thereabouts in tremendous quantities. This material is a fairly uniform hard rock carrying about 25 to 30 per cent iron as magnetic oxide, which is to be separated from the fine-ground waste material by magnetic separators. The enriched oxide is then mixed with a little fine fuel and sintered into a porous clinker, producing a high-grade, pure ore, especially low in sulphur and excellent for blast furnaces.

When it is remembered that only 40 years ago phosphorus was giving as much trouble as is sulphur today, one might safely predict that before many years the latter can be as closely controlled and eliminated as the former is in the basic process, a process by the way essential for working the most important European deposits—the high-phosphorus Minette and Cleveland ores.

One can hardly predict the successful line of attack. Sulphur may be found to have high affinity for some special slag, more fusible and therefore less costly in fuel than our present ones, high in lime. Or some new ferroalloy may be added to molten steel, eliminating sulphur as ferrosilicon washes out the oxygen. Another interesting possibility, and one which is theoretically sound, is the direct reduction of iron ore to sponge iron by carbon monoxide gas at comparatively low temperature, a heat so low in fact that the sulphur compounds are unreduced and are slagged off in their original state in the subsequent melting, never having entered in the metallic iron.

In view of this history of metallurgy, a history of peculiar dignity, the individual engaged in the art may well wonder what part he may have in its future development. What can one man do with rather limited experimental equipment? The most talked of researches now are the co-operative researches planned on a large scale and requiring the labor of many investigators. The author would like to point out, however, that research cannot be planned, any more than any expedition can be outfitted to locate a new gold lode.

Metallurgists are unabashed in the face of these difficult and important problems in view of the most curious fact that fundamental discoveries are usually made with absurdly meager equipment, not at all in keeping with the magnitude of the subject. The Curies did not need to finger an electron to discover radioactivity—indeed no man or woman ever will. Nor did Newton weigh a planet before announcing the law of gravitation—in fact it is rumored that all he needed was to see an apple fall. Faraday discovered electric induction—the foundation principle of all we know as electrical engineering today—with a magnet and a loop of wire. More recently, Benedicks proved the highly controversial and baffling question of thermoelectric currents in a homogeneous metal by merely cutting a wire in the center and crossing the ends. One may thus well derive inspiration and courage in reflecting on the important work which is possible even with a moderate amount of instrument equipment when reinforced with a large amount of intellectual resource.

Therefore it is rather futile to give instructions to researchers who will find out these real epoch-making things yet hidden. But as a matter of fact, only an infinitesimal number of findings belong to that

class. The rest are merely adaptations of known principles, or an arrival at a given point in well-mapped territory by less devious route. With such utilitarian things most modern seekers are concerned.

Perhaps the principal rule to adopt would be: Don't become discouraged because others have tried and failed. A sufficiently minute search through the literature would doubtless reveal at least one reason why any given scheme would be foolish. One or more men may have actually recorded failures in attempting the same path you plan to follow. But it would be as bad to turn back because some one else had not successfully traveled the route as it would be to abandon the expedition in discouragement on arriving at the first obstacle. Still, don't become discouraged at the wrecks along the way.

Nor do we need to be discouraged because what we find has no apparent utility. Rest assured that each bit of information will eventually be used in the advance of civilization—indeed may be delayed sometimes by its lack. Faraday could not have prophesied the end of his electrical research; no more can we today. Not long ago metallic calcium of high purity was manufactured. It had no apparent use. A considerable industry, however, has since come to depend upon the so-called tungar rectifier, whose principal parts are metallic calcium, a bulb of special glass, a spiral of tungsten wire, an electrode of artificial graphite, and a little argon gas. Twenty years back not one of these essentials was available.

The educated man in metallurgy is, if nothing more, doing yeoman work in the ranks, pushing the art forward. Only a month or more ago, public recognition was given to the graduates of Sheffield University in that English steel center, in view of their indispensable services in keeping that city at the forefront in steel manufacture. But more than this, the metallurgist can keep open the door to information. The secret process is too often old and wasteful—he who keeps out proper inquiry too often keeps out information—and sometimes the manufacturer is ashamed to let the world know he is still nursing obsolete methods.

THE PYROMETER FROM THE STANDPOINT OF THE USER

By Arthur N. Armitage*

(Presented by Title at Philadelphia Convention)

Nearly all the articles dealing with the subject of pyrometers have been written by people who were financially interested in some particular make of instrument, and however impartial they may have tried to be, they have at least failed to mention imperfections or disadvantages to be found in the particular type of installation in which they were interested.

The thermocouple principle is now almost universally employed as a means of measuring heat in the steel industry except for very high temperatures such as the temperature of molten metal in which case, optical pyrometers are used.

All the makes of pyrometers now on the market have their good points, the question is, which kind, if any, is the best for our particular purpose. It is possible that a system which would be satisfactory for use in the ceramic industry would not be of much use for the treatment of steel.

The indicating and recording millivoltmeter perhaps is the simplest

* Assistant metallurgist, Mesta Machine Co., Pittsburgh.

measuring instrument and the one which requires the least attention from the operator. We now have a single point recorder which requires almost no attention except to keep the clockwork wound up and a little cleaning and oiling when the roll of paper is renewed.

The millivoltmeter employed should be of sufficiently high resistance to take care of the resistance of the lead wire which varies with the temperature to which the lead wire is exposed and also with the length of lead wire used. If the instrument is located near the furnace and compensating lead wires are used, a low resistance instrument can be employed and will give sufficiently accurate readings, but if it is necessary or advisable, as is often the case, to locate the measuring instrument at some distance from the furnace, an instrument of much greater resistance will be necessary to read the true electromotive force of the couple.

A pyrometer system arranged so that couples can be made up at the plant probably is more economical in operation than the one in which the couples must be purchased completely assembled. The different parts, including the time of the operator taken to make up and calibrate the couples, do not cost nearly so much as new couples, and new couples must be calibrated also. The heads can be used repeatedly, then again, couples can be shortened a few inches when the ends become burned off or when the couples are found to be incorrect on checking.

We have an instrument in connection with four coal-fired pit furnaces which was made to be used with shunted couples, and as we often have to run the furnaces at very high temperatures to reach the A_{cm} point in hyper-eutectoid steels, the couples were very easily destroyed and new ones had to be bought.

It was found that cromel-alumel wire had a millivolt-temperature curve that was very similar to that of the couple of the instrument in question. By carefully calibrating the cromel-alumel couple against the couple intended for the instrument, a shunt was made for the millivoltmeter so that correct temperatures were recorded and couples made up at the plant could be used.

These couples would read correctly only between the temperatures of 1550 and 1800 degrees Fahr.; the slight error recorded when the heat was rising and falling was not important. A double throw switch is arranged so that either one of two shunts can be used, one to be used for high temperatures and the other for the draw.

First some trouble was had in twisting the ends of the wire being used to make up the couples, especially with the No. 8 wire. It was found, however, that by clamping the two wires about $\frac{1}{2}$ -inch apart in an ordinary vise with about $1\frac{1}{2}$ inches to be twisted and, after first hammering the wires for the first turn of the twist then holding them with a monkey wrench, a twist could be obtained equal to that of couples received from the factory.

An electric weld is better than an acetylene weld for couples and we are welding our couples by using the rheostat on the optical bench. Disconnecting the wires from the arc lamp, we connect two insulated wires to the rheostat, one of them to the couple and the other to a discarded piece of carbon from the arc lamp. A package of borax completes the outfit and good welds are very easily and quickly obtained.

A single point recording millivoltmeter is used in connection with six drying ovens used for drying molds, and the recorder can be transferred to any one of the six ovens through a six point switch. A prac-

tice has not been made of using recording temperatures at the drying ovens and the instrument is used as an indicator, occasionally, however, the recorder has been used overnight on special work. To do this a recorder instead of an indicator was installed.

At first the firemen were not interested in the pyrometer at the drying ovens but now they swear by it and the molds are thoroughly and uniformly dried. The only occasion for complaint regarding the condition of the molds since the pyrometers were installed was, when the light in the instrument case burned out during the night and the firemen could not see to read the temperatures.

It has been found that when the different pyrometers are kept in order, the operators at the furnaces depend almost entirely on them, which is as it should be, especially on coal-fired furnaces where the physical strength of the operators is the principal requirement. The pit furnaces previously referred to are operated by a gang of huskies who refer to the temperature as so many pounds instead of degrees.

They are given a schedule showing the required temperature at each hour as for example:

10:00 a. m. 1200 degrees Fahr.
11:00 a. m. 1210 degrees Fahr.

In annealing or treating very large forgings or castings, special effort is made to have the hot junction of the couple touching the metal being treated and protected somewhat from the direct flame. For castings such as press cylinders, bare couples are used so that they can be twisted or turned in any desired direction. For instance, a bare couple about 12 feet long is placed with the hot end of the couple inside the cylinder so that temperatures on the inner wall can be obtained. The couple is then covered with wet fire clay along its length to protect it from the flame.

The temperatures at the car type furnaces are recorded on 12-point potentiometer recorders except when we have occasional demands for temperatures higher than 1600 degrees Fahr. In a treatment where temperatures higher than 1600 degrees Fahr. are desired the recorder is run to this point, the couples are then removed from the furnace and the temperatures taken with a pyrometer ball. Our own pyrometer balls are made from wrought iron stock and are very accurate so much so that if there is occasion to doubt the accuracy of a couple during the progress of a heat, a ball is taken at this point. If the couple and the ball do not check, the offending couple is substituted for another.

The potentiometer is undoubtedly the most accurate instrument for measuring temperatures, line resistance can be neglected and closer readings usually can be made. The type of potentiometer provided with a cold junction compensator is very dependable, the only objection being the care required to keep the instruments in working order.

In making up couples of the iron-constantin type, it is desirable to use some kind of powder in the protecting tubes to exclude gases as the couples last much longer when the powder is used. We use dry fireclay and the only trouble experienced was in getting the powder into the pipes. The couple heads of this particular type were evidently designed with the idea of keeping everything out of the pipes but we finally decided to make up some tubes with the hot end threaded instead of plugged. The thermocouple was first inserted by standing the pipe upside down, pouring in the powder and closing the end of the pipe with a pipe-cap.

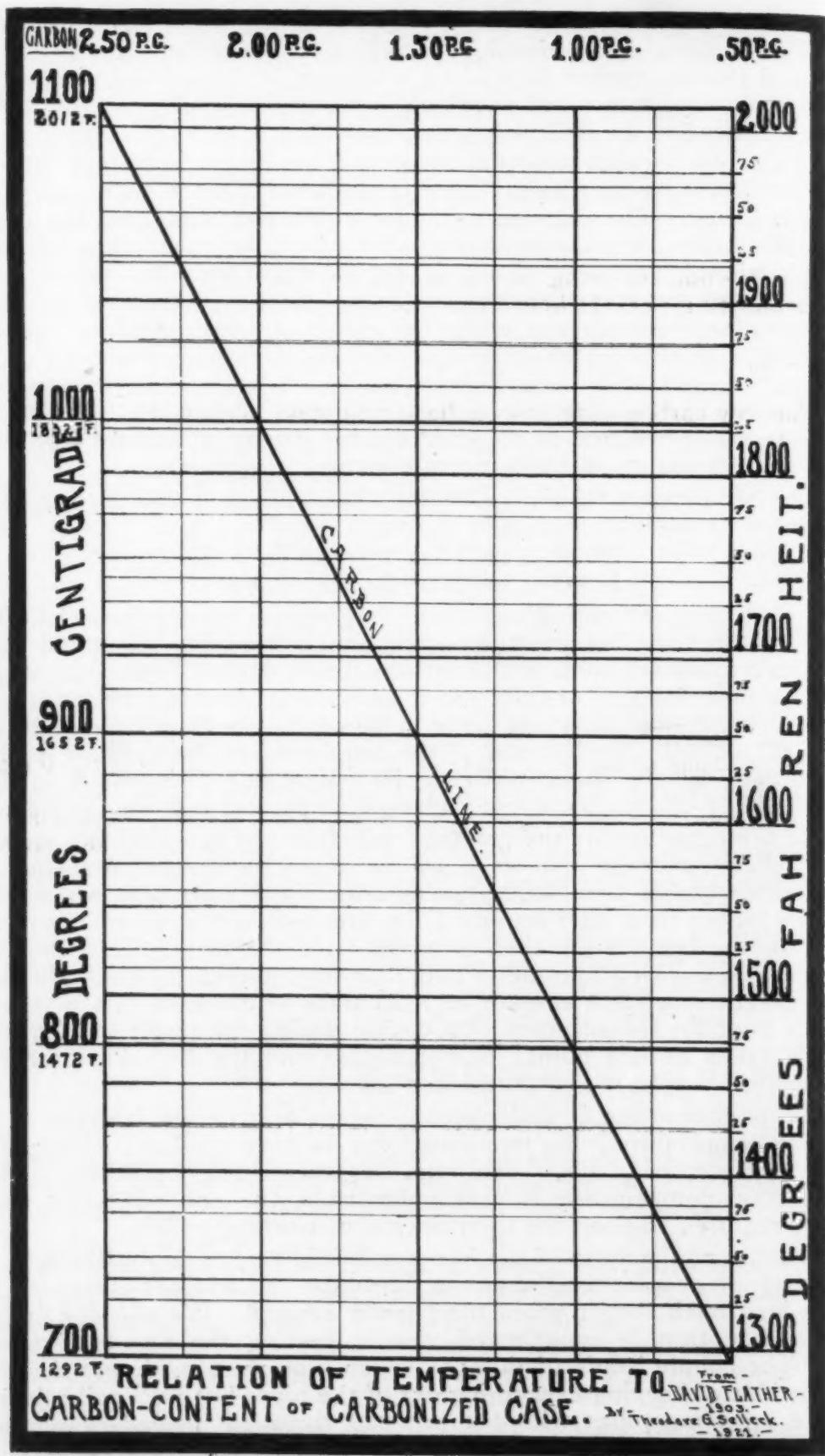


Fig. 1

THE CARBONIZING PROCESS—RELATION OF TEMPERATURE TO QUALITY OF CASE AND CORE

By Theodore G. Selleck*

In discussing this subject it is important that we have a clear idea, first of all, as to what is meant by the terms "case" and "core", of carbonized steel, and what their physical and chemical characteristics are.

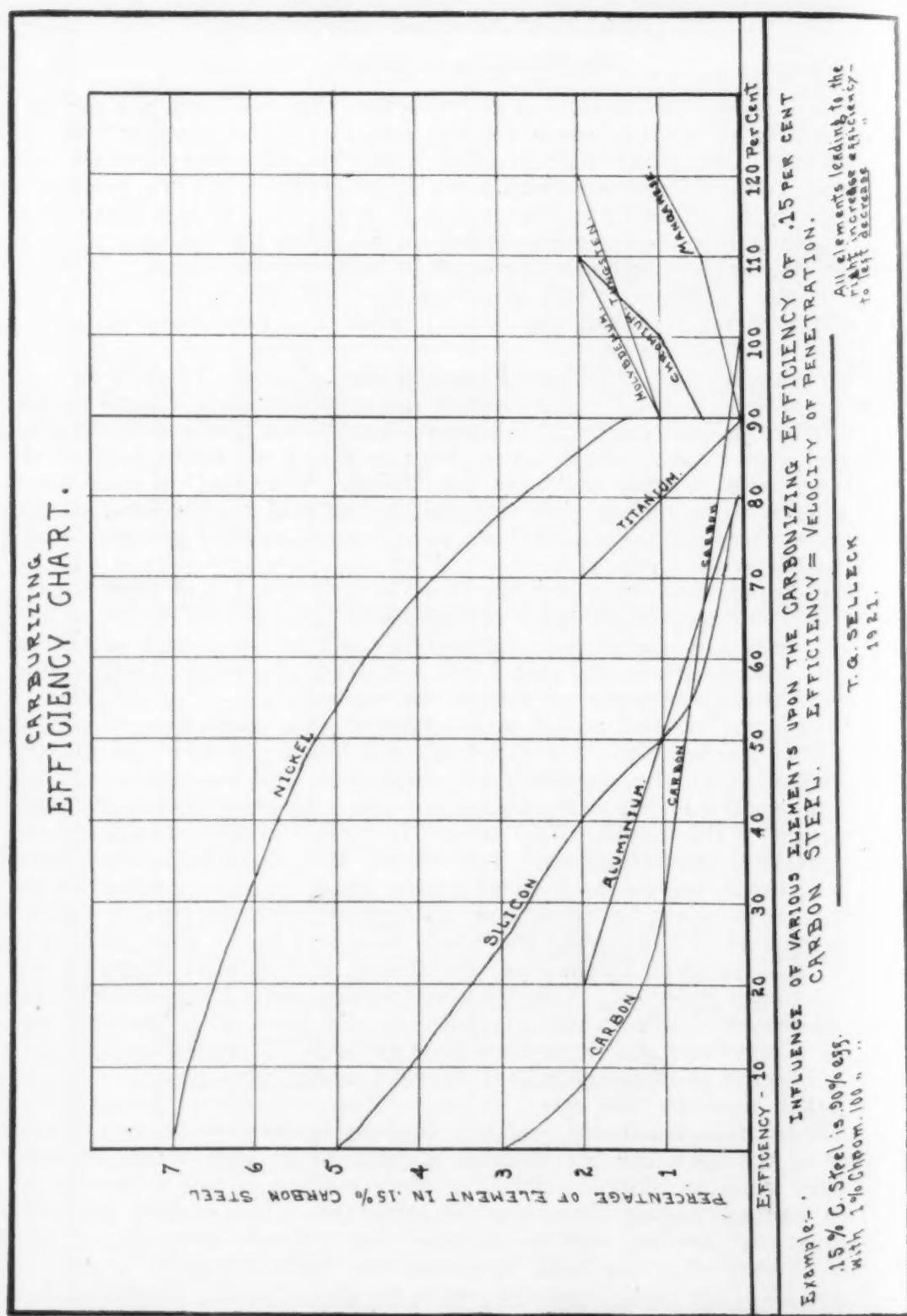
In all carbonizing operations there is or should be left a portion of the metal in its original condition; that is, a part of the metal is not allowed to carbonize, being prevented from so doing by the shortening of the carbonizing period; hence the steel in that section remains or should remain in the condition it was in before the operation began. Such section of the metal is called the "core", while the carbonized surface is called the "case".

The low carbon core of case hardened steel imparts the ductility necessary to resist breaking strains, while the case furnishes a hard surface for resistance to wear; this combination furnishing parts that combine those two important qualities as no high carbon steel could, and at the same time permits rapid and easy machining. This fact, of economical machining of parts out of soft material, is the real reason for the high importance the process has attained as a manufacturing process during the last quarter of a century.

The temperatures at which the steel is carbonized, and heat treated, have a very marked effect upon the physical qualities of both the case and core; since the operation of carbonizing, under the most favorable of conditions, always leaves the metal in a condition of almost absolute ruin, if no heat treatment were to follow the carbonizing. Fig. 3 shows a fracture of a bar of steel which was subjected to a carbonizing temperature of 1750 degrees Fahr. for a period of 6 hours. It has had no heat treatment but is in the condition in which heat and the carburizer left it. It was cooled in the carbonizing pot and was then broken to show the structure of the metal. This sample is typical of all carbonized steel before receiving heat treatment; it is brittle, and also very soft, and its physical qualities are not as high as a poor grade of gray iron would be. The structure is coarse by crystalline throughout, with no definite division between the core and case; and the whole structure seems to be lacking in cohesion, and suggests to the eye, something that is just ready to fall apart of its own volition. A microscope reveals only a slight difference in the conditions visible to the unaided eye, and shows that the structure of case is a bit closer and somewhat finer grained. The lack of cohesion, however, is more pronounced when observed under the glass.

In order to make this metal of any value, it becomes necessary to subject it to heat treatment. If the highest quality is desired in the structure of the core, the heat treatment must be at such a temperature, and of such a nature as will place it in the condition it was in before the operation of carbonizing disturbed its structure. This means that the metal must be heated slightly beyond its critical temperature and quenched. After this has been done and the highest quality is desired in the case also, the same treatment must be given for the higher carbon case. When these treatments have been given the steel a fracture of the metal will show as in Fig. 5.

*Consulting metallurgist, 4046 Jackson Boulevard, Chicago. This is the second of a series of 10 articles on "The Carbonizing Process" written by Mr. Selleck.



It is sometimes the practice of casehardeners to quench steel direct from the pot at temperatures very close to the carbonizing temperature. While this sometimes is practiced without any serious results, it is poor

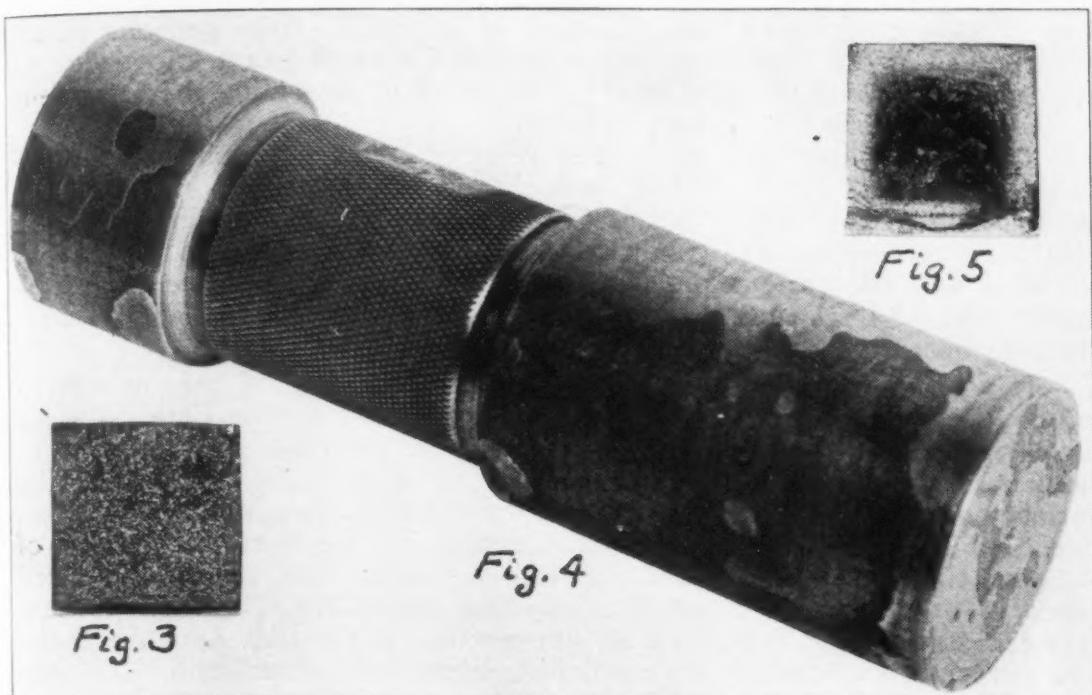


Fig. 3—Fracture of Steel Bar Subjected to a Carbonizing Temperature of 1750 Degrees Fahr. for 6 Hours. Fig. 4—Plug Gage Carbonized at High Temperature and Quenched in Water Directly from Pot. Notice the Spalling. Fig. 5—Same as Fig. 3 Heated Slightly Beyond the Critical Temperature and Quenched

practice, and parts so treated never possess anything approximating the quality they should were they handled properly.

Other casehardeners allow the parts to cool slowly in the pots and reheat for a single quench. In such cases sometimes great economy is effected if the loss of parts through failure to pass final tests does not absorb all the saving of an extra quench.

Quenching from the pot may result in very serious losses, as will be seen in following paragraphs of this article, and the single quench treatment may bring such a variety of troubles that it would take too much space to enumerate them; but if it must be done, the operator should know first, whether the core or the case is most essential to the value of the part; second, he should know approximately at least, the carbon content of both the case and the core; and his treatment should be based upon one or the other for there is no one temperature which can give maximum quality to both. With some manufacturers and their hardening-room assistants, it is often a matter of getting things hard without reference to any special quality that the work must show and in such cases it is of little use to give advice; but to the casehardener who has quality of work in his mind the writer suggests that he always makes sure of every point, especially in the heat treatment of his carbonized parts, for as shown, carbonizing itself absolutely ruins the structure of steel. Thus it is up to the steel treater to redeem it.

The effects of high temperatures, both in carbonizing and in heat-treating, are more marked in the quality of the case than in that of the core, because the core is always the same steel after carbonizing that it was before, and has the same critical point. The case, however, has assumed a different chemical constitution, different physical qualities, and

has become a complex steel, instead of a simple, homogeneous metal that it was in the beginning, and it requires a more exact knowledge of its constitution and physical qualities in order to determine the treatment it should have for its highest refinement.

Carbonized steel has often been referred to as a "double steel", because of the two zones of "low carbon" and "high carbon" set up in the carbonizing of the metal; but it is more complex than a simple double steel. If we consider the conditions, we find in the chemical make-up of the case and the various physical conditions that are established in the application of heat thereto during the carbonizing as well as the heat treating operations.

It will be well for us to consider here something of the manner in which the case is made up, and its true relation to the core. As we have learned, in a previous article on the subject, the carburization of steel is produced by the introduction of carbon into the metal from the surface toward the core; we find that during this introduction of carbon that that element is always more abundant at the extreme surface of the steel than it is at any point between the surface and the uncarbonized core; in other words, there is a gradual lessening of carbon content between surface and core, and no abrupt line of division between them. The percentage of carbon that will be present in the surface of the case depends most largely upon the carbonizing temperature to which the steel was subjected and partly, to the manner and nature of the heat treatment given it subsequent to carbonizing.

The accompanying chart, Fig. 1, shows the relative amount of carbon that steel will absorb when carbonized at various temperatures. It will be noticed that this chart is based upon the researches of David Flather, who in 1903 in a technical journal, stated that: "Iron, saturated with carbon at 700 degrees Cent. can contain only 0.50 per cent carbon; at 900 degrees Cent., 1.5 per cent carbon; at 1100 degrees Cent., 2.50 per cent carbon." These values are given as for the saturation of the iron in the metal; that is, the iron at those temperatures will contain the percentage of carbon indicated. In the application of the carbonizing process there is to be considered the fact that there is always a saturation of the metal on the extreme surface and that saturation is maintained as long as the temperature is maintained. From that saturated portion of the metal the carbon diffuses into the metal just as water will diffuse into wood when the surface of the wood has become saturated with it; or, if it is desired to visualize the process, take a pail of water and with a medicine dropper run a small stream of bluing around the edge of the pail just above the water and notice how the blue saturates the water at the edge and gradually diffuses itself toward the center of the fluid. In like manner does the carbon find its way into steel; and the saturation gives way to gradual diminution of carbon content as it approaches the core.

In the preceding paper the theories of the operation of the process were discussed, and among them the theory of "molecular migration". In connection with that theory there is another old one that fits in well with it and makes the chart in Fig. 1 more easily understood. This is the theory that all carbon is dissolved at the surface of the steel, in all carbonizing operations, and is not deposited from gases entering the metal.

Some of the phenomena observed in the manipulation of the process

seem to point to some such condition existing at the surface of the metal, for if we take a piece of carbonized very low carbon steel from the carbonizing pot while it is at a carbonizing temperature, and quench it quickly enough to avoid any possible chance of the carbon burning out of the metal when it comes into contact with the air; and have the quenching medium a very fast one, such as brine or ice water, we find a concentration of carbon at the extreme surface greater than we ever experience in the cooling of the steel in the carbonizing mixture and reheating, or even in the ordinary quenching direct from the pots. The carbon is there as a solid solution which has not had an opportunity

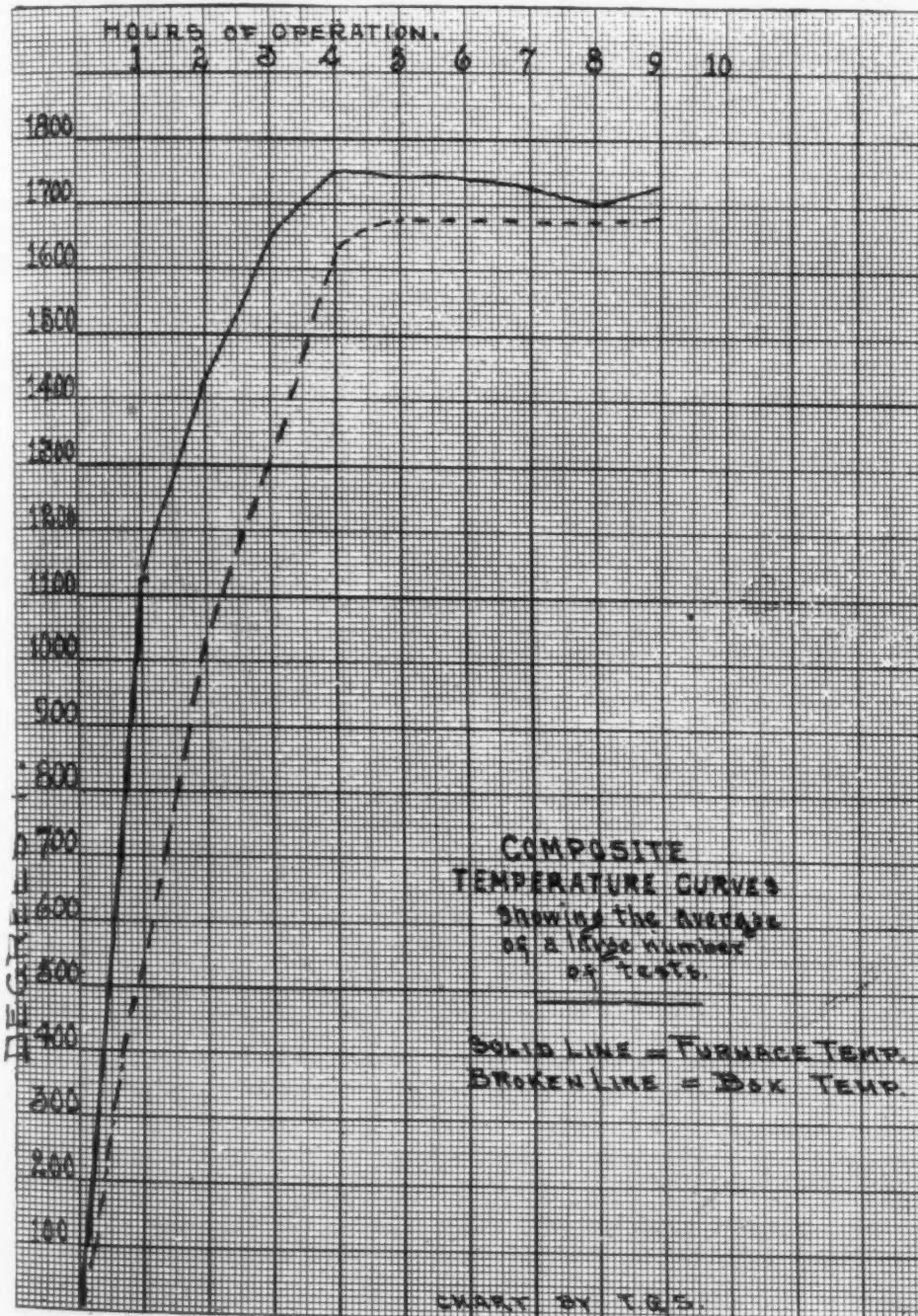


Fig. 6—Curves Showing Comparative Temperatures Inside and Outside Carbonizing Boxes During Carbonizing Operations

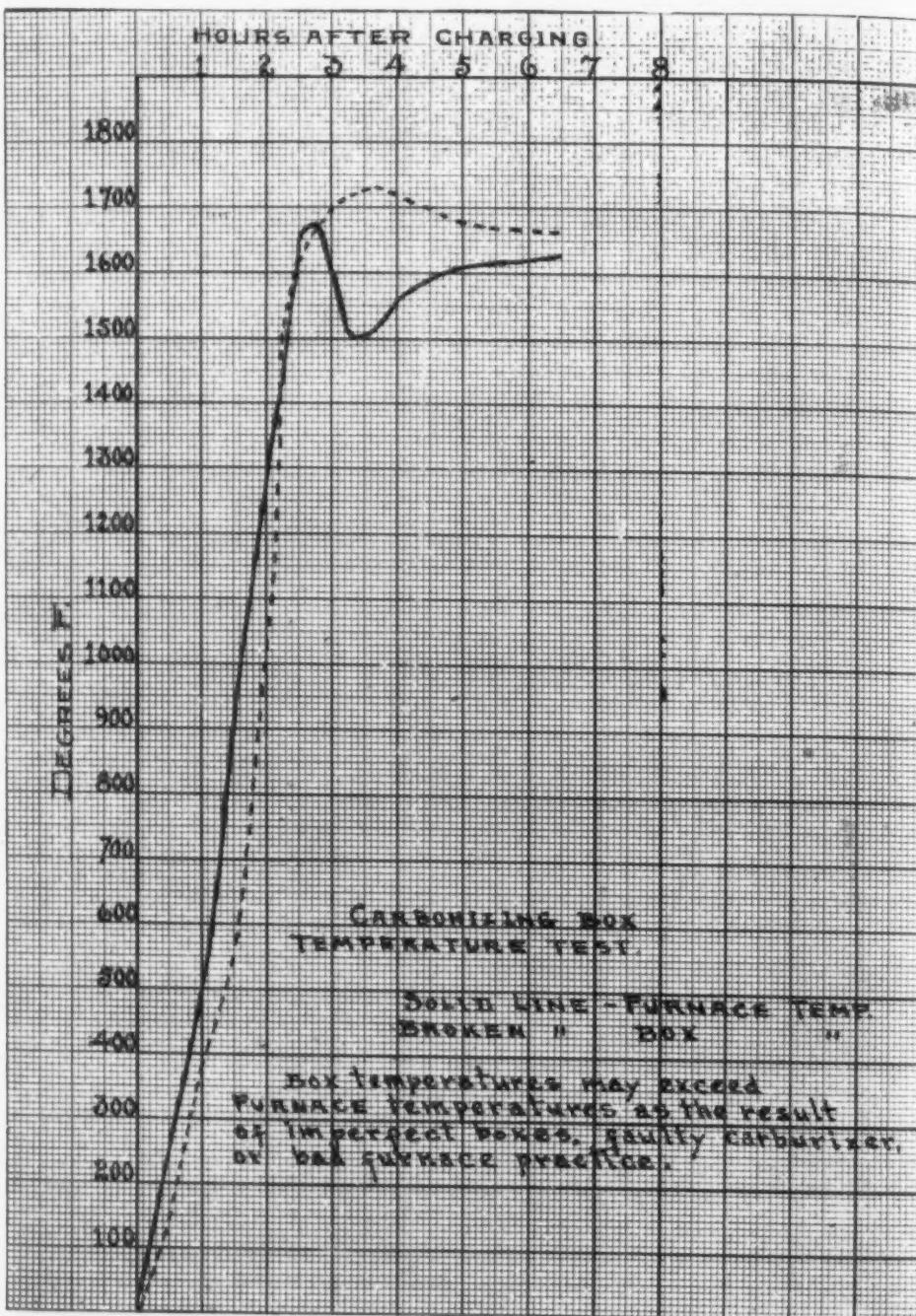


Fig. 7—Curves Showing Excessive Temperature Established Inside Carbonizing Boxes After Furnace Temperature Has Been Lowered

to diffuse into the metal, and it is always there in a percentage equal to the saturation point of the metal.

This saturation and diffusion of carbon is responsible for the great complexity of the case referred to; it establishes in the carbonized portion or case what are recognized as three zones of varying carburization. These are known according to their carbon content as the hypo-eutectoid, eutectoid, and hyper-eutectoid. The first of these zones, hypo-eutectoid, is that containing the lowest percentage of carbon, and lies next to the core; its carbon content is under 0.87 per cent; the next, or eutectoid

zone, is that portion of the case lying next to the hypo-eutectoid, and contains 0.90 to 0.95 per cent carbon; while the hyper-eutectoid contains above 0.95 per cent of carbon. Thus we see that if we carbonize at temperatures above 900 degrees Cent. (1562 degrees Fahr.) we are quite sure to have a hyper-eutectoid case, and if we keep below that temperature we may have a case of most any desired carbon content.

In practice we would have difficulty in establishing an exact schedule of temperatures for the various requirements in carbon content of our work, but we may be assured that if we carbonize at a certain temperature we will have in our case, for a certain depth at least, the amount of carbon the chart indicates. Such depth is sometimes so slight as to make it difficult to get a chemical analysis, but photomicrographs often prove such values in quite a convincing manner.

After steel has been carbonized the heat treatment of it must be governed by the nature of the service that the steel will be obliged to render. If a hyper-eutectoid case has been established and the requirement is for extreme hardness without the need of any particular toughness in the sharp edges or the lighter sections of the material, the quench for the case should be at the critical temperature of approximately 1.00 per cent carbon steel, without any subsequent draw; but if the wear to which the parts are to be subjected is abrasive in character such as gears, or dies, the parts should be given a draw of approximately 400 degrees Fahr.; the exact temperature of the draw can only be determined when the scleroscope or Brinell hardness requirement is known. It is a matter usually for the operator himself to determine by test, since there are always variations in steel, and in conditions within the shop that make it impossible to establish exact rules for hardening steel that may be followed successfully by all steel treaters.

In submitting these considerations on the subject of the relation of temperature to the quality of case and core, there is still another matter of vital importance touching upon this question. That is the effect which certain elements have upon the carburization of the metal when such elements are introduced as alloys.

Fig. 2 is a chart showing the carbonizing efficiency of steels containing certain percentages of such elements as are usually alloyed with low carbon steel. The carbonizing efficiency is based upon the velocity of penetration that it is possible to obtain in the alloyed steels when compared with plain carbon steel. It will be noticed that the curves leading to the right, from the meridian line are the elements which aid the absorption of carbon by the steel, and so increase its efficiency, while those leading to the left are the elements that retard penetration, and lessen the carbonizing efficiency of the metal. In endeavoring to balance these different effects we find it necessary to increase the carbonizing temperatures for those elements which retard carburization, and lower it for those that accelerate carburization. In heat treatment after carburization we find that we must pursue the same course, giving milder treatment to the alloys that add efficiency, and higher temperatures, and more severe quenching to those that lower the efficiency of the metal in carburizing. For instance, a high nickel steel will stand a much higher temperature for the normalizing of the core than a high chromium steel will and a harsher quench.

There is, however, one exception to this rule that must be mentioned here most emphatically, and that is in the case of carbon where

the carbon content runs above that of mild steel, the metal should receive the same treatment given the higher alloys, such as chromium, manganese, etc.

A single quench for carbonized parts always should be avoided where it is economically possible, and should never be chanced where the carbonizing temperature exceeds 1650 degrees Fahr. if quenching from the pot is necessary for such practice results so often in the absolute loss of parts so treated, that the chance of avoiding trouble is really so small that it is not worth considering. Fig. 4 shows a photograph of one of a

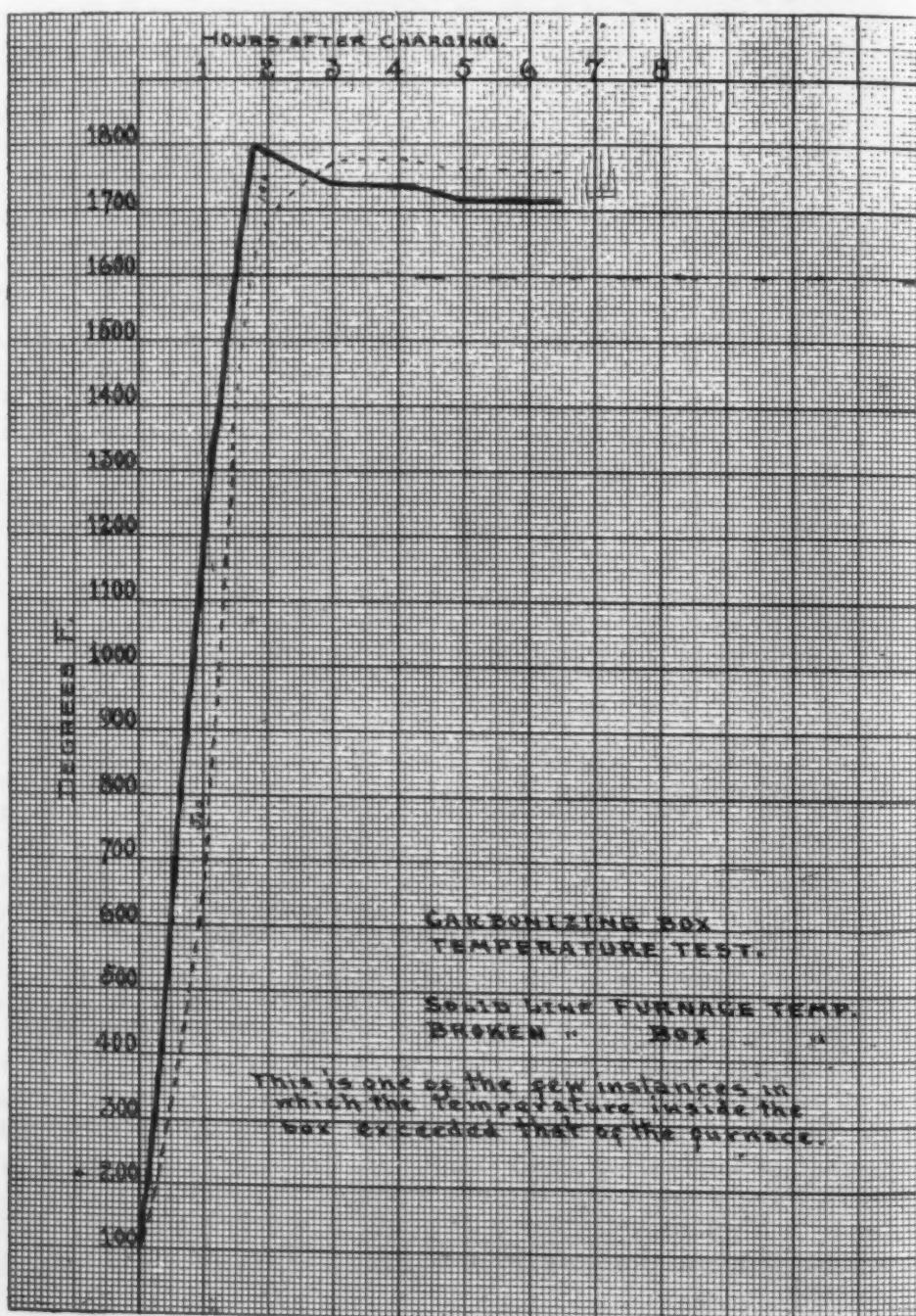


Fig. 8—Curves Showing Temperatures Inside and Outside Carburizing Box, the Box Being Imperfect

number of plug gages carbonized at a high temperature, supposed to be around 1650 degrees Fahr. but apparently very much above that range, and quenched from the pot. These gages were reduced perceptibly in their diameters by the spalling off of a case of very high carbon from their entire surfaces. The explanation of the trouble is quite clear, and is found in the explanation given in the preceding paragraphs of the chart in Fig. 1. Carbonized at very high temperature, (the degree in doubt), the gages were taken from the carburizer while at their carbonizing temperature and quickly quenched in water. The saturated surface of the metal had no chance to yield any of its surplus of carbon by diffusion to the layers of metal laying next to it, or unite by any welding process to the less carbonized portion, and in the severe quench it became a loose cylinder of metal of a character that possessed no strength or homogeneity, with the result that it just fell away. This is an excellent example of "enfoliation", a fault that is common to the practice of single quenching from the pot.

If these parts had been allowed to cool down slowly in the carbonizing material, and had then been given a quench at the proper temperature, probably they would have been saved. However, it is not always that direct quenching is responsible for spalling or enfoliation, and high carbon content and excessive concentration of carbon at the surface of the metal are not always accompaniments of this sort of failure. We often see the same condition on steel parts that are ground after hardening, when the fault can be traced directly to faulty grinding; then again it may occur in carbonized parts made from nickel steel with a carbon content above 3.00 or 3.50 per cent, even when the parts have been cooled slowly in the pots, due to high concentration of carbon in the surface of the metal, in which case treatment recommended by some steel treaters is to heat the metal slowly for the heat treatment of the parts after carburizing; or in the carbonizing period, to add to the carbonizing time sufficient to allow a gradually diminishing temperature. That is, if the carbonizing temperature is 1750 degrees Fahr., and the carbonizing time is 8 hours, 2 hours additional should be added to the time to allow for gradually reducing the temperature to 1650 degrees Fahr. The reduction should be gradual to permit the carbon to diffuse through, or into the inner layers of the metal, thus avoiding the high concentration of carbon at the surface.

Surface cracks, showing on polished pieces of carbonized steel, may be traced also to the use of improper carburizers, or the improper use of good carburizers. The photo shown here was carburized with a nationally known commercial carburizer, and one that has been used for a long time by the company in whose plant this failure occurred, and by a casehardener whose service with the company has been highly satisfactory. Undoubtedly in this case one of those very rare conditions of excessive internal combustion was the underlying cause of the failure; while among a certain class of casehardeners the theory of a higher temperature inside of carbonizing boxes than outside is pretty well fixed. Tests very carefully made have proven that, while such a condition may occur, it is very rarely established, unless a very faulty carburizer is used, or the pot or box is in bad condition and permits the ingress of oxygen, or pots are used without covers and violent combustion proceeds from the exposure of the carburizer to the furnace gases. If a carburizer containing inorganic carbon with hydrocarbons is used, such combustion may

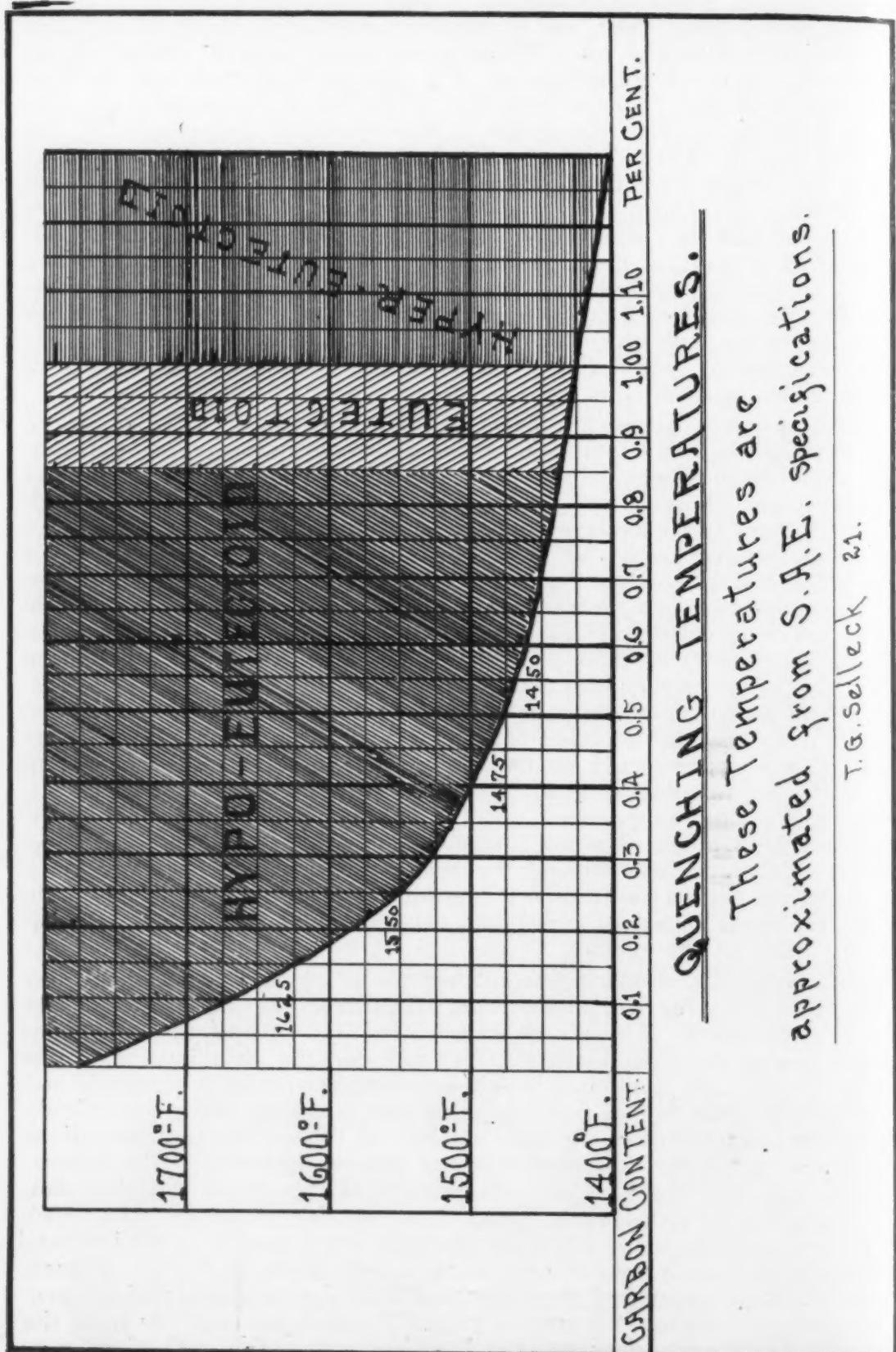


FIG. 9.—Quenching Temperatures for Steels of Various Carbon Contents

take place without any of the other conditions being present; if bone is used, as the writer has frequently seen it, in pots without covers, excessive temperature may be established in the pot. Just why a casehardener will use a pyrometer in his work under such conditions, the writer can not understand; he says that his temperature within the pots is higher than outside or greater than his pyrometer indicates, "anywhere from 100 to 200 degrees Fahr.", he does not know just how much. A pyrometer is an investment under such circumstances that will never pay interest; and yet they are the ones who usually spend the most time watching the pointer, have the most trouble and more frequently write to somebody a 1000 miles away to tell them what to do to overcome their failures. A chart is shown in Fig. 6 giving the comparative temperatures inside and outside of carbonizing boxes during carbonizing operations; these are composite curves made from a long series of tests. This chart shows that under regular conditions the inside of carbonizing boxes is at a much lower temperature than that of the furnace.

There are conditions, as stated, when an excessive temperature is established inside of carbonizing boxes, and will even increase there after the temperature of the furnace has been lowered. One such test is shown in Fig. 7. In this case it will be noticed that the temperature inside of the box was higher than that of the furnace chamber for a period of more than $3\frac{1}{2}$ hours, and while the furnace temperature was falling rapidly, the box temperature was rising almost as rapidly. The cause of this condition was a very combustible carburizer made chiefly from coal products containing oil and other hydrocarbons, which produced gas at very low temperatures and at such velocity that the sealing of the box was of no use. Fig. 8 shows the result of another test of the same character, in which the trouble was not caused by the carburizer but by an imperfect box. In this case a small blow hole in the cast-iron box permitted the entrance of enough oxygen to stimulate the combustion of the organic matter of which the carburizer was composed. However, in the composite curve shown all of these various conditions are represented in the average indicated.

The writer does not wish it to be understood that he considers this composite curve a fair average of the conditions obtaining in general practice of the carbonizing process, for these tests were made under conditions which perhaps would not be considered the average, and he believes that under the best modern shop conditions a better result than this would be shown by similar tests. The author does believe that in the average casehardening plant the operator is very much off in his estimate of the time required to bring carbonizing boxes to the temperature of the furnace, as indicated by his pyrometer, especially when little care is shown in the proper placing of the thermocouple. If some operators would take the pains to check up on themselves, they would meet some surprises. In these charts it will be noticed that the variation of temperature between the inside and outside of the boxes was very pronounced, sometimes for several hours, and the composite curve shows that as an average, there was a difference between the two temperatures of about 125 degrees after 4 hours of heat.

The boxes used in these tests were of standard size, of the following inside measurements: 4 inches wide, 6 inches deep and 18 inches long. Various carburizers were used to determine the comparative heat conduc-

tivity of various compounds, more about which we will consider in later articles.

The relation of temperature to the quality of case and core is a very direct one, as indicated by the straight carbon line shown in the chart in Fig. 1. This is for the carbon content of the case and should indicate to the operator the heat treatment of the case. In Fig. 9 is shown the quenching temperatures of steels of various carbon content, which will be useful to the operator who desires knowledge of the proper temperature for the refinement of the core or case. This chart does not take into consideration the presence of any alloying elements in the metal.

There are no hard and fast rules for the treatment of carbonized steel, beyond that of the strict observance of the critical temperatures of the metal. This is at times difficult to determine without scientific apparatus for the purpose, and the average casehardener can not avail himself of the use of those important and expensive instruments; so it becomes necessary for him to use his common-sense, and proceed slowly in all his operations until he knows he is right. Where a critical point is in question, and no equipment for determining it is at hand, practical tests should be made until the fracture of the metal indicates the proper temperature is established. It is always better to sacrifice a few parts for the establishing of proper heat treatment than it is to go ahead blindly and perhaps sacrifice thousands of them later with the added sacrifice of a customer's business and good-will.

STANDARDIZING SPECIFICATIONS FOR TOOL STEEL

By Charles M. Brown*

(A Paper Presented Before the Pittsburgh Chapter)

A curious and remarkable state of affairs exists in the tool steel trade. For a number of years efforts have been made by individual consumers and by technical societies to write standard specifications for carbon tool steel with practically no effect on the manufacture of tool steel and without any marked influence on general buying, while at the same time high speed steel has become practically standardized without effort on the part of any individual or society to draw up a specification.

This has been brought about on the one hand by the failure to take into consideration to any great extent the really decisive factor, namely, cutting ability, whereas this same factor has been responsible for reducing high speed steel to a standard article.

The first attempt to draw a specification for tool steel of any kind, so far as we know, was made some 15 or 16 years ago by the General Electric Co., Schenectady, N. Y. This effort undertook to divide carbon tool steel into three distinct grades or qualities to be determined by the chemical analysis, with the additional provision that the steel must be made by the crucible process and must be free from the common mechanical defects such as pipes, seams, etc. This example since has been followed by a number of manufacturing companies and by several railroads, and while these efforts constitute a step towards standardizing for the particular shops for which the specifications were drawn, there are so many differences in the analyses and stipulations such that if the practice grows

*Vice President, Colonial Steel Co., Pittsburgh.

the result will be the opposite of standardizing. A greater tendency than ever will result towards specializing in the manufacture of tool steel for particular users—a thing which on every account should be avoided. Prompted by the example of these individual consumers, several of the technical societies, notably the American Society for Testing Materials, have attempted to write a specification for tool steel which would be standard for general use.

Almost without exception these attempts at writing specifications have been opposed steadfastly by the toolmakers. Several reasons for this are evident. To begin with, the fear exists for the effect they would have on the prestige of long established brand names. Proper recognition should be given to those steel makers who by years of careful study and determination have produced efficient and dependable brands, but this need not enter into the discussion of the practicability of standardizing. The steelmakers, however, have found practical objections of two kinds, both more or less justified and founded on good reasons. The first objection is that none of these specifications have provided any way for determining the real essential in tool steel, that is, its cutting quality.

When the steelmaker has had placed before him specifications prepared by some user, the natural question was "Why do you want steel of this kind?" The natural answer is this: Because we have been using entirely too many kinds of steel and we believe that a steel made to this specification will simplify our work and give better results." To this the steelmaker replies, "The specification as you have drawn it does not agree with any steel that we regularly make, but if you insist upon obtaining steel to your specification we will be glad to make it, in which case no doubt you will assume all responsibility for its doing the work." This is not unreasonable if the specification is what it claims to be, a method of providing good steel. This obstacle has been overcome in the specifications of the United States Navy Department by providing for actual shop working tests, and by making awards on the basis of these tests rather than by strict fulfillment of their chemical provisions. In almost all other cases the steelmaker's final reply has been: "If you expect me to continue to guarantee that the steel will do good work, you will be wiser if you leave all the details of the composition or manufacture to me."

The second objection relates to details. The carbon content in any individual specification seldom agrees with the standard practice of the steelmaker. In any process of melting more or less off-carbon heats, will result, especially in the crucible process where the practice of casting every pot separately into one ingot is followed, with the result that as many different kinds of steel and as many different percentages of carbon as there are pots in the furnace will result. The extremes in these carbon ranges, in some cases will be wide, and even where the ladle process is used and the contents of all the pots in the furnace are emptied together and cast into two or three ingots, still some chances of variation in the carbon content exist. Charcoal, which is used for adding the carbon, is very volatile and some portion of the charge will escape. The crucibles used are about 55 per cent pure carbon, some of which is lost during the melting and enters into the steel, a larger amount in new crucibles than in old ones, and these factors sometimes result in a greater or larger amount of carbon than ordinarily expected. The standard practice allows for 10

points range, thus heats which come outside of the standard range are considered off-heats and unless a market be found for these, they must be remelted. This increases the cost of manufacture.

It must be remembered also that carbon tool steel is used for a great variety of purposes under widely different conditions. Some operations require a very hard steel and others just the reverse, toughness having more importance than hardness. The steelmaker cannot know, in the majority of cases, for what purpose the steel will be used, and consequently must regulate the carbon content according to that experience which has proved to be the most common tools made of specified sizes and shapes. For example, round bars commonly are used for taps, cutters and similar tools, and might contain from 1.10 to 1.20 per cent carbon; flat bars mostly go into die work for shearing and pressing metal for which 1.00 per cent carbon gives good results; chisels made from octagons should be about 0.80 or 0.90 per cent carbon; and square bars used for hammers, sledges and similar tools about 0.75 or 0.80 per cent carbon. By arranging a schedule of this nature a point is found for steel of any carbon content between the highest and lowest extremes. Usually, if a buyer comes with his own specification stipulating one range of carbon and suitable for his own particular shop conditions, he is almost invariably asking for steel which is not the maker's regular standard and which requires him to undertake a special manufacturing operation. These statements are made in explanation of the opposition which has prevailed on the part of the steelmakers at attempts to standardize up to this time, and to explain the lack of progress.

Before going further it is best to give a definition for the term "tool steel," a term which often is indefinite. As we shall use it, tool steel is any steel for cutting tools or implements which are hardened and tempered.

Studying the field thus outlined, we will find that standardization has already taken place to a marked extent. Wherever figures of proved performance can be determined accurately and the decision is based on the cutting service of the steel, the result has been a rather common agreement between buyers and makers upon a standard form of composition. Word passed from the manager of one factory to another and from them to salesmen and back to the makers has brought a pretty general agreement on certain types of steel as best fitted for certain uses. A number of standard types are already familiar to us.

High speed steel practically is standardized in two types. The first of these and the one most generally in use is known as 18 per cent tungsten-vanadium steel and will be found to conform to the following composition:

	Per Cent
Carbon	0.55—0.75
Manganese	0.20—0.40
Silicon	0.10—0.30
Chromium	3.00—4.00
Tungsten	16.00—18.00
Vanadium	0.50—1.00

Probably from eight to a dozen different makes of steel now are on the market conforming to this standard composition.

The second type of tool steel is lower in tungsten and higher in vanadium, conforming to the following composition:

	Per Cent
Carbon	0.55—0.75
Manganese	0.20—0.40
Silicon	0.10—0.30
Chromium	3.00—4.00
Tungsten	12.00—14.00
Vanadium	1.50—2.00

This second type, although not so commonly known nor having as many supporters, nevertheless is to be obtained in several brands and is considered suitable for some purposes. A standard type of finishing steel is known by this name, and is procurable from a number of different manufacturers. It contains tungsten from 3.5 to 5.0 per cent and carbon sufficiently high to enable the tool to hold a keen cutting edge. Twist drill manufacturers use for their carbon drills a standard steel containing carbon about 1.10 to 1.25 per cent and about 0.50 per cent chromium.

Oil hardening steel is a standard type and can be obtained from a number of different manufacturers. It has the following composition, based on results proven by the original promoters on this type of steel:

	Per Cent
Carbon	0.80—1.00
Manganese	1.25—1.75
Silicon	0.25—0.40

This type might be classified in another way as a manganese alloy tool steel. It is true that oil hardening steels of different composition are made and offered on the market, but their success in no way approaches that of the standard type generally used.

For hot heading work on bolts and rivets, two standard types are available, one corresponding to a low grade high speed steel containing 11 to 13 per cent tungsten but with a lower carbon content than would be suitable for high speed steel cutting tools. In place of this, a number of manufacturers are offering and producing good results with steel containing 0.75 to 0.85 per cent carbon and about 3.5 to 4.5 per cent chromium.

For rivet driving sets there was at least during the war some approach towards standardization as the Emergency Fleet Corp., the largest consumer of steel for this purpose, put out a specification calling for steel to contain a definite amount of carbon, manganese and vanadium.

It will be noted that no reference has been made in the above to the question of phosphorus and sulphur, in spite of the fact that books would be required to record all the controversies which have been waged as to how much sulphur and phosphorus was permissible. Judgment as to the permissible limits of phosphorus and sulphur has changed considerably during recent years, it now being conceded that larger amounts of phosphorus and sulphur safely can be permitted than was formerly believed. As a matter of fact, in some cases, it is possible to get phosphorus too low as certain tools which require great surface hardness are helped by a slight inclusion of phosphorus beyond what was once thought desirable for the very finest steel. It is also noticeable that all of the standard types outlined are alloy steels containing one or more alloys upon which they depend for certain marked and valuable characteristics. This then reduces the obscurity and need for further consideration.

to the problem of plain carbon tool steel, although in one way it would seem as if the need was less urgent.

Taking a period about 25 years ago before the possibilities or qualities of high speed steel were discovered, practically speaking, all tools were made from plain carbon steel with the exception of a very small amount of what was then known as self-hardening steel, the forerunner of high speed steel. Consequently, carbon steels were called upon to perform a wide variety of uses from shearing hot billets or heading rivets to drilling stone, cutting wood, paper, leather and so on to metal cutting tools such as drills, taps and dies. For some of these purposes the steel had to be extremely hard. For others, hardness was not nearly so important as toughness. It is quite natural then that to meet all of these various purposes there were developed and put into use a great many kinds and varieties of carbon tool steels, but today the use of high speed and other alloy tool steels has restricted and made the uses of carbon steels more simple. When any difficult metal cutting job is to be done we use high speed steel. For most of the other operations where carbon steel most often proved unsatisfactory, one or other of the alloy steels above referred to have been adopted. Comparatively speaking, it is for the easy jobs that carbon tool steel is used today. It would seem, therefore, as if the selection of carbon tool steel would be much simpler than ever before.

The question as to the advantages of having definite standards for tool steel from the point of view of the user hardly can be denied. Modern methods, gas or oil-fired furnaces, the use of pyrometers giving accurate records, etc., have made it necessary to use steels of similar and known characteristics. It must not be supposed that the introduction and use of high speed steel and other alloy tool steels have made the use of carbon tool steel unimportant. Such is not the case. No accurate statistics of any kind are available to show how much tool steel is either made or used because up to this time there has never been any agreement as to exactly what shall be included under the term "tool steel" in many shops it is customary to use the term "tool steel" to mean plain carbon tool steel and not high speed steel.

When we define tool steel as any steel made for cutting tools or implements which are to be hardened we cover a great many applications which never would enter into most peoples' minds. For instance, not only steel for mining drills, but also for tillage implements, molds and shares on plows, for cutting knives on mowing and reaping machines, axes, sledges, screw drivers and many other tools, the enumeration of which would take too much time. Twenty years ago all of these steels were made by the crucible process. The growth and tonnage became so large that it was impossible to take care of the business satisfactorily in such small units and the open-hearth process is now relied upon to produce a part of the tool steels of this kind.

Twenty years ago tool steel was synonymous with crucible steel and all the soft center plow steel, all the mowing machine knives, all mining drills steel and all die blocks, were made by the crucible process, where today all of these steels are made by the open-hearth or electric process, as well as a large quantity of the steel used for shear blades, punches and some other tools. They are, nevertheless, just as truly tool steels as ever before, requiring the same great care and careful

manipulation in working and undergoing the same practices in all processes outside of the melting. Omitting, however, the agricultural implement tool steels and mining drill steels from calculation, probably it is safe to assume that there is four to six times as much tonnage of simple carbon tool steel produced as there is of high speed steel, so that its economic place in industry is still of great importance.

In approaching the problem of ideal standards, how much should be taken into consideration? Should it rest alone on chemical composition or include restrictions on process of melting, of materials to be used, or other steps in the manufacture? Analysis not only is useful but essential with respect to steels which contain one or more alloys, and which depend upon these alloys to give the characteristics essential to maximum service, but in plain carbon steel analysis is of little importance to the user. Analysis enables the manufacturer to produce a more uniform product, and where the ladle process of casting is used and a few ingots are produced, it is possible to make a complete chemical analysis of every heat and thus prevent or check any irregularities which might otherwise creep in. But to the user of plain carbon steel, analysis tells little if anything, except the amount of carbon contained and even that is not of great importance. For steel in some applications, it is desirable to have a close range of carbon, but in many cases a wide range can be used without affecting either the heat treatment or the performance of the tool itself.

The amount of phosphorus and sulphur which are permissible depend a good deal on the kind of base material used. Steel made from the best puddled iron can carry safely a higher percentage of sulphur and phosphorus than one made from a scrap mixture such as open-hearth plate punchings or shearings. Chemical analysis will not disclose careless manufacture. It will not disclose mistakes or omissions, improper melting, overheating in rolling or annealing cannot be disclosed by chemical analysis. Proper performance of these steps is absolutely essential to produce tool steel of the proper quality for any use.

Should the specifications call for any particular process of melting? The crucible process of melting is the oldest known method and remains the best, because of the means which it affords for careful handling and watching, due to the small units employed and the 100-pound charge in each pot. But as has been already pointed out, where consumption in any line of tools grows to a large tonnage the crucible process usually has given way to a more economical one. And undoubtedly it will continue to be so, although a place for crucible melting in finest qualities of steel will exist for a long time to come. The electric melting process has been recommended strongly as producing steel of equally good quality, but its definite place in the industry is not yet settled. The open-hearth process, as has been pointed out, is used largely. A process is but a process after all, and is not more fool proof than heat treating, thus poor steel can be made by any method.

As to the question of specifying materials, this is open to like objection. Manufacturers of tool steel honestly differ widely in belief as to what materials produce steel of satisfactory performance, and since as has been found out, so much depends on the skill and care in all the steps of manufacture, it will be impossible to predict that the use of any specific raw material would necessarily of itself result in first class steel.

In any effort to establish national specifications, the co-operation of the steel manufacturer should be sought and obtained, for without it the proposition becomes more difficult. We are of the opinion that the manufacturer should be allowed as much freedom as possible in the choice of processes or of materials, in view of all the widely different beliefs and practices now being used.

Place the most importance on the service which the steel gives. The question is how to provide tests which will determine this service. Cutting ability of course, is the first feature. For some time manufacturers of testing machines, have been working with the hope of developing a machine which would test specimens of steel for cutting ability accurately and rapidly, but unfortunately up to this time no machine has been developed which is entirely satisfactory. It is to be hoped that success in this line will not be long deferred. Until such time it will be necessary to depend to a large extent on actual performance tests made in the shop. It has been found possible in other steels such as structural steels and alloy steel for automobile use to determine the value by physical tests showing the tensile strength, elasticity and reduction of area.

On the other hand, very little investigation has been made to determine what physical tests might be made to show the value of tool steels. For example, for tools such as twist drills or taps, might not torsion tests be valuable and indicative of the quality of the steel? In another way, compression tests would be valuable, the greatest difficulty in this instance being that many steels when hardened and tempered have such strength that it is practically impossible to break them on any of the machines now in use.

Up to the present time, therefore, it would seem that practical possibilities for standardizing types of tool steel exist in defining certain definite types or grades of steel, as follows:

1. High speed steel.
2. A tungsten alloy finishing steel.
3. A manganese alloy oil hardening steel.
4. A chromium alloy tool steel.
5. A vanadium alloy tool steel.
6. A molybdenum alloy tool steel.
7. Steels containing two or more alloys such as chrome-vanadium or chromium-tungsten.

This list might be extended from time to time as new types or varieties are found successful.

This leaves at the bottom the last, carbon tool steel, as a general proposition and it seems wise to leave it at that. In other words, not to attempt to write specification which will distinguish between different qualities or grades of carbon tool steel until more exact means of measuring quality are found, but to provide for one general type or class. It is true and must not be overlooked that there will be wide differences in quality in carbon steels and these differences will continue to result from the experience, skill and care of the manufacturers, for which it appears that no possible method of distinguishing can be found unless or until some simple, cheap and expeditious way of testing cutting value is devised or by some method found for making use of the test of physical properties.

RELATIONS BETWEEN THE PHYSICAL PROPERTIES OF
STEELS AND THEIR ENDURANCE OF SERVICE STRESSES

By James E. Howard*

(A Paper Presented Before the Lehigh Valley Chapter)

Shreve in the preface to his translation of some of the results of Spangenburg, published by Van Nostrand in the year 1876, made these remarks:

"The results of these very important experiments have been before the profession for some years, but, strange to say, seem to have attracted no attention; and tests of iron and steel still go on for the purpose of determining their elasticity, their elongation under strain, their ultimate strength and other qualities, while Wohler and Spangenburg's experiments show that it is very doubtful that these bear any proportion to the durability of the metals".

These remarks of Shreve, made 45 years ago, are well to keep in mind since they describe a condition which has continued in a degree down to the present time. Efforts are made currently to impart high physical properties to steels in their primitive state, the relations of which to the endurance of service stresses are in a measure conjectural. It is believed, generally that the possession of these high primitive properties improves the steel for useful purposes. If such opinions did not prevail there would be no justification in demanding those high properties in the specifications governing the acceptance of the metal. Going a step further, the query may be made whether the imparting of these special properties is in all cases beneficial, whether negative results may not be encountered, if perchance the treatment happens to be injudicious.

Existence of the American Society for Steel Treating carries with it the inference that steel in its natural, annealed state is not in its best condition to meet all of the requirements of the arts. Those properties which inherently pertain to steel in a well worked and annealed state inadequately meet the needs of service. A combination of physical properties distinctively modified over those which naturally attach to the steel as governed by its chemical composition, increases the permanent value of the steel, basing the deductions upon the results of the testing machine with a single application of load increased to the limit of rupture.

It would seem properly one of the functions of this society to advance information along certain lines and firmly establish relations which are now obscure. A distinction is made between the working of steel and the treating of steel. As steel treaters you are expected to regulate the properties of the steel after it has been properly shaped by the operations of forging, or rolling, or perhaps after machining, and bring the steel into a state of greater efficiency.

The mere fulfilling of the requirements of a given set of specifications does not present itself as the vital feature unless it is shown that the specifications themselves are right. The framing of specifications depends upon antecedent knowledge of the behavior of the steel under those conditions which it will be subjected to in service. Such information is not as accessible to the steel treater, as a rule, as it is to the steel user. The use of steel, therefore, furnishes one of the best illustra-

* Engineer-physicist, Interstate Commerce Commission, Washington.

tions of the need of cordial, reciprocal relations between the steelmakers or steel treaters and the steel users.

Steel is most commonly used for resisting loads or stresses which may be those of tension, compression or shear. The stresses may be constant, intermittent or in alternate directions. In the abstract, the problem of the steelmaker or steel treater is to furnish a steel which will endure the widest range of loads or stresses without loss of integrity. In approaching the subject in this manner it is preferable to speak of strains instead of stresses. Strains represent the deformations which attend the application of stresses. In a way, it is immaterial how the loads or stresses are provided, the deformations of the steel are kept within limits.

In judging the endurance of steels to service conditions it is simpler to think of strains than stresses, although under most conditions of loading a definite ratio exists between the two, as expressed in the value of the modulus of elasticity. A strain of one thousandth, not 0.001-inch but one thousandth of the length of the member under consideration, represents a stress or load of 30,000 pounds per square inch, according to the value of the modulus of elasticity taken at 30,000,000 pounds per square inch.

It is obvious that when steel is ruptured, certain adjacent particles are separated beyond their range of activity; the bond connecting them has been severed. The difference between a low carbon and a high carbon steel in respect to their elastic limits is that one has a greater elastic range than the other. This elastic range under some circumstances is a measure of the stress which the steel is capable of enduring although this statement must be made guardedly and subject to limitations and qualifications. If this were not done, the elastic limit of the steel in the direction of loading would be an index of its durability and ability to endure service stresses.

It is desired to emphasize this manner of regarding steel according to strains rather than according to stresses. It is the deformation or movement of the metal within itself in respect to the relations of adjacent particles to each other which constitutes the vital feature; the strain which the steel endures. A strain is produced by the application of a load or stress. One is the cause the other the effect. It is the effect with which we are concerned. A condition of loading may exist when adjacent particles are not separated and under such a condition it is probably safe to say rupture cannot be accomplished however great the stress may be. Such a case is presented in the cubic compression of steel, that is, when compression stresses are simultaneously applied in three directions. Modified conditions are presented in impinging pressures between a sphere of large radius and the plane surface of a block of steel of large cubical dimensions. The maximum intensity of the pressure in this example may be very great but the graduation of pressure from the maximum at the center of the impinging area to its periphery may be such that no two adjacent particles are separated beyond their normal range of activity, or beyond the radius of molecular action as it is called. A common example of this action is found in wheel pressures on the heads of steel rails. Unconsciously this feature is considered in railway engineering, in the use of wheel loads which from a metallurgical point of view are excessive.

Providing steel is not strained beyond a given amount, no reason exists for doubting its indefinite endurance. It is necessary, however, in

this connection to take into consideration not only the strains which result from external loads but also the state of internal strain of the steel. This second factor is one which has been overlooked generally, in engineering structures, little consideration has been given the influence of internal strains in the metal. These strains are just as tangible as those which result from external loads and it is believed they account for cases of rupture which are not adequately explained by reason of the magnitude of the external loads. There are examples in which internal strains appear to exceed those resulting from external sources, the overlooking of which therefore neglects the principal factor in the cause of failure of the steel.

It is held to be a matter of deep concern as to how and when these internal strains are introduced and their magnitude. They may result from cooling strains during fabrication of the steel, that is by thermal means, or they may be the result of mechanical work in the cold state, such as cold rolling or cold drawing. The general effect of such treatment whether thermal or mechanical, is to increase the rigidity of the steel against permanent deformation, or modify its rate of deformation under stresses which exceed its elastic limit and approach rupture.

Necessarily internal strains can only exist in couples. An internal strain of compression must be balanced by an internal strain of tension. Variations in magnitude may exist, since a larger volume of metal in a state of tension may balance a smaller one in compression. Graduations in strains of the same kind in different parts of the section also occur. Measured strains show the mean values in the detached strips on which the observations are made, hence such values are below the maximum.

Measured strains necessarily represent those which prevail in a considerable volume of metal. They are obtained by establishing gaged lengths on different parts of the periphery of the steel member after which strips are detached by machine tools. The expansion or contraction of the strips show whether that part of the steel member was in an initial state by compression or of tension respectively. The resilience of the steel, that is the strain displayed by the detached strips, show the magnitude of the internal strains. Internal strains expressed in their corresponding stresses amount to many thousand pounds per square inch.

These bulk values are conservative values and commonly fall below the values which are reasonably certain to have existed. A change in the density of the steel seems to account best for the presence of internal strains, in respect to mass formation. There are reasons for believing that intermolecular strains exist, the aggregations of which are represented by the bulk values. It is but a step further to infer that internal strains may attain such a degree of magnitude that spontaneous rupture of the steel may occur, and when such an example of rupture occurs, there will be no display whatsoever of ductility in the steel, notwithstanding its ability to display normal elongation and contraction of area in the tensile test.

It is well known that spontaneous rupture does take place in hardened steel, not only at the time of quenching but later thereby releasing some of the internal strains. When internal strains exist, and since they must be in couples, it follows that the elastic limits first will be reached locally; in one part of the steel, if loaded in tension, in another part, if loaded in compression, since the internal strains

and those resulting from the external load of the same kind must be added together to show the total strain in any one part.

Heat treatment in respect to the quenching of the steel must perforce introduce internal strains. Subsequent drawing of the steel relieves some of them, substantially all, if the drawing becomes an annealing operation. The modified physical properties remain in evidence and in degree according to the states at which these operations are suspended. There is nothing mysterious or occult about these modifications in physical properties, although experience is required to attain certain pre-determined results, in the primitive tests of the steel. But as Shreve remarked 45 years ago there is nothing in these primitive tests, in themselves, to indicate what permanent advantage has accrued from effecting these changes in properties in respect to the steel enduring service stresses which do not resemble the methods or manners of a tensile test. The purport of these remarks is to call attention to what must constitute proof of the advantages of employing different methods of treatment.

A great wave is passing over the steel industry in the effort to secure steels of superior efficiency. Alloy steels are competitors with the more familiar, earlier carbon steels. High speed tool steels have been known for some time. Their introduction has effected great economy in machine tool operations, at least in respect to the rapid work which such tools are capable of performing. The ultimate economy is sometimes menaced by the condition imparted to the machined members. The objections which have been urged against punching and shearing also apply to steel members after very heavy chips and feeds have been taken, such as are possible in the use of blue-chip tool steels.

Alloy and heat treated steels are presenting themselves as candidates for favors in other lines of engineering. The automobile industry has stimulated effort in this direction on account of the saving in weight of steel by calling upon it to endure higher fiber stresses. In airplane work the saving in weight is of greater consideration. In the latter line of construction, however, it is not pleasant to contemplate the consequence of subjecting the working parts to endure higher fiber stresses than the metal is capable of sustaining over periods of long duration, the particular feature upon which primitive tests on physical properties do not afford sufficient data.

These remarks will hardly be considered as an enthusiastic endorsement of the indiscriminate treatment of steel, conducted without a full realization of the gravity of the features involved. Suspending a one-ton weight from a slender wire furnishes a forceful illustration of the fiber stresses which are involved when steel is loaded to a maximum. It only represents, however, the stresses which a comparatively small range in temperature is capable of introducing in steel. The control of so powerful an agency as heat demands the utmost skill and painstaking care.

Steel music wire of a fine size, No. 12 music wire gage, has been found to show a tensile strength exceeding 450,000 pounds per square inch. This wire when released from tensile stress, prior to rupture, would be capable of a resilient recovery of not less than 15 thousandths of its length. It represents the maximum range in elastic extension and recovery which has come to the knowledge of the speaker. This wire, in the upper octaves of a piano-forte, is stressed 150,000 pounds or more

per square inch, representing an extension of 5 thousandths of its length. Music wire is a carbon steel of about 0.85 per cent carbon. Its high strength is acquired as the results of drawing through several numbers without annealing.

In compression, hardened steel has been found to sustain a stress of 600,000 pounds per square inch, representing a compressive strain of 20 thousandths of its length. Failure of this specimen occurred by reason of the bursting of the reinforcing buttresses, throwing an eccentric stress on the hardened center. The radial extension of the specimen, according to Poisson's ratio should be in the neighborhood of 6 thousandths of its diameter. In this comparison of the maximum elastic extensions of steel it appears that the direct extension in the music wire presented a higher value than the indirect, radial extension of the compression specimen.

As to the effect of cubic compression on steel, that is, compression applied in three directions simultaneously, the highest pressures reached in experiments conducted by the writer caused no appreciable permanent effect. Pressures up to 117,000 pounds per square inch were employed. These experiments were made in a hydrostatic press having thick walls. The temporary reduction in volume of the steel, if such occurred, was too small to be determined. Carefully boiled water when under this high pressure was reduced in volume over 15 per cent.

So far as known cubic compression of any degree is without permanent effect on steel. Even a sample of Portland cement was unaffected by a stress of 100,000 pounds per square inch cubic compression. These observations, so far as they went, confirmed the belief that loss of integrity of steel is the result of excessive tensile strains between adjacent particles; that efforts to force the particles closer together result in no permanent changes in physical properties.

Alternate stresses of tension and compression present quite another problem over those of stresses in one direction only. It has not been possible to realize the high values displayed by the metal in the individual tests of tension and compression. In fact, only about one and a half thousandths elastic movement in each direction, or three thousandths aggregate movement has been found in the case of repeated alternate stresses, for periods of long duration. Stresses in certain grades of steel in repeated alternate stress tests have been endured for 100 to 200 million repetitions, under loads up to 45,000 pounds per square inch. Under higher fiber stresses the number of repetitions of stresses which caused rupture was much less.

A repeated alternate fiber stress of 45,000 pounds per square inch appeared to be the limiting stress for indefinite endurance using carbon steel bars of different carbon contents, ranging from 0.10 to 1.00 per cent carbon and regarding 200 million repetitions as equivalent to indefinite endurance. The feature was not fully established but there were indications that a saturated steel, in reference to its carbon content, about 0.90 per cent carbon, possessed greater enduring qualities than steels of higher or lower carbon. These tests were conducted a number of years ago. They were inaugurated 33 years ago, and some 400 bars were tested under different fiber stresses at normal and at high temperatures, puddled iron, cast iron, hot rolled and cold rolled steels being included in the series. A steel bar of unusually high elastic limit, acquired by heat

treatment did not on that early occasion show superior endurance to the plain hot rolled steels. It has been said in explanation of those results that heat treatment in early days was not as well understood as at the present time.

Notwithstanding the fact that the elastic limits of the experimental bars used in the repeated alternate stress tests were considerably above the fiber stresses employed in many of the tests yet it was found that prior to rupture some slight permanent sets were displayed in each case. As the limiting number of alternate stresses was approached, the bars showed permanent deflection sets, which increased toward the last. These deflection sets amounted to but few thousandths or 0.010 inch on a chord of 10 inches. Their presence, however, raised an interesting query, whether they were not indicative of some intercrystalline strain, and through their presence led to a higher local strain than the fiber stress on the test bar called for. In other words, the question was raised whether the steel was actually ruptured by a reduced fiber stress or whether some state of internal strain did not contribute toward rupture by an intensification of the nominal strains within the steel.

It was found that steels ruptured by repeated stresses while at a blue heat endured a much greater number of repeated stresses than the same steels when tested at atmospheric temperatures. It had also been shown in an earlier series of tests, made at different temperatures, that the steels were stronger at a blue heat than when cold. Their greater endurance at a blue heat seemed to connect the value of the tensile strength with durability of the steel, although the apparent fiber stresses were below even the primitive elastic limit.

Another feature of interest was brought out in these tests and those of another character conducted in those early days. It appeared that exhaustion of ductility preceded actual separation or rupture of the steel under conditions of repeated stresses and also when subjected to the cold rolling action of wheel pressures. This is a matter which is regarded as of importance. It suggests the possibility of restoring the steel to its primitive state and prolonging the endurance of repeated stresses. As entertaining as this thought was, efforts at that time did not bring about a favorable result. Provided a steel bar will endure a certain fiber stress for 100 million repetitions before rupture, it is of interest to ascertain whether the progress of rupture admits of being arrested at some intermediate stage, the steel being relieved of its internal critical condition and renewed. Its ductility admits of restoration. The annealing of iron chains is an example. The question therefore is whether a process which is capable of restoring ductility is also capable of restoring the steel from the effects of repeated stresses, renewing its primitive ability in the endurance of repeated stresses.

In hot worked steels there is substantially an equality in the elastic limits of tension and compression. A series of experiments was conducted on the effects of overstraining steel bars by alternate tension and compression, not as a beam is strained by alternate bending loads, but by applying direct loads in an axial, longitudinal direction. The total elastic range in stress, tension plus compression, without loading beyond the elastic limit in either direction, amounted to 100,000 pounds per square inch. This range was curtailed upon overloading the bars in either direction. Overloading in either direction greatly impaired the value of the elastic limit in the opposite direction, reducing the total elastic range. The observations were not conclusive as to whether time without change in temperature, effected a restora-

tion in the values of the two elastic limits, of tension and compression respectively.

It has long been known that a temporary reduction in the modulus of elasticity occurs in overstrained steel, from which there is a recovery after the lapse of time. Ascending and descending stress-strain curves in overstrained steel follow different paths. There is an area of lost work shown by the diagram which must mean that a state of internal resistance has been caused by the overstraining loads, while the recovery from this state indicates a probable molecular readjustment within the steel.

The behavior of lead furnished a suggestive illustration, but one which has not been detected in steel, although perchance research has not gone far enough to do so. It is as follows: A lead cylinder taken from a pig with the axis of the cylinder coinciding with the longitudinal axis of the pig, when upset endwise displays a greater tendency to flow radially in the direction of the major axes of the lead crystals. The result of upsetting is an elliptical shaped specimen, but this occurs when the upsetting is continuous. Providing a partial upsetting is given the cylinder followed by an interval of rest after which the upsetting is renewed, the result is then different. The cylinder now presents about the same tendency to flow radially in each direction, and further upsetting results in forming a specimen substantially of circular cross section. Overstraining followed by an interval of rest has changed the properties of the lead crystals*

Annealing results in a pronounced change in the dimensions of a steel forged or rolled shape. The successive annealing of a section of a steel rail, at 1500 degrees Fahr. caused a shortening of its length, which referred to a 33-foot rail amounted to nearly 1.2 inches. These observations were extended to the effects of annealing a cube taken from a forging. The cube contracted, when annealed, far more in the direction in which it was drawn out in the forging than in its other two dimensions. These observations made with a strain gauge revealed a movement which was unexpected, at least by the author. Other observations on the effects of quenching steel from a high temperature made at this time showed the difficulties which are experienced in operations of this kind in maintaining the shapes of hardened and annealed steel members unaltered. It is impracticable to quench a uniformly heated cube and preserve the fixed relations which the sides of a cube bear to each other. The different sides and edges each are differently affected when plunged into the quenching bath.

The difference in the rate of transmission of strains and the rate of conductivity of heat is a pronounced factor in the heat treatment of steel. The dilation of the metal by heat lags much behind the prompt transmission of strains. A proper realization of these differences which prevail is of advantage in conducting the heating, quenching and drawing of steel shapes.

Internal strains result from heat and mechanical treatment. The magnitude or saturated state of the internal strains is doubtless limited by the elastic limit of the steel. Higher internal strains have been observed as the result of heat treatment than those caused by mechanical means. The acquiring of internal strains by steel probably is associated with changes in density of the metal. The only known method of determining either the presence or magnitude of internal strains is to machine-cut the steel into small detached parts and note the changes in dimensions which then occur. It is, of course, known that internal strains will result from a variety of

*Editor's Note:—Strained lead recrystallizes slowly at room temperature.

treatments but in the absence of information upon antecedent conditions inspection of the steel does not indicate whether or not strains exist therein. In respect to microscopic examination it is not discernible whether the steel is in a state of repose, or whether in a state of internal tension or compression. The great value which would attach to a method of examination by means of which the internal state of strain of a steel member in place could be determined is apparent. Such a method would enable the strains which exist in all kinds of engineering structures to be ascertained and the margin of safety to be judged.

So far as known there is no difference metallurgically or physically between internal strains which result from certain ranges in heat or mechanical treatment and those which are due to external loads. If such is the case, then rupture may be accomplished either by heat, mechanical means, the application of external loads, or by their combined action. Cold rolling which distorts the grain of the steel and drastic heating and quenching which changes the microstructure represent extreme conditions which qualify this statement.

From the point of view which a consideration of the influence of internal strains leads to, it seems logical that heat or mechanical treatment is a step in the direction of ultimate rupture. It is quite certain that heat treatment is capable of causing spontaneous rupture and examples of such effects are by no means uncommon. The effects of heat treatment are effaced in whole or in part by annealing. Annealing also relieves the steel of internal strains. The essence of heat treatment appears to reside in the introduction of internal strains in the steel. It is a serious question to what extent such treatment is desirable and the purpose for which the treated steel is to be used. Such a question might best attach to airplane construction, where the penalty of failure is most obvious.

The question may be asked: What is the peculiar state of a steel which has had properties imparted to it foreign to its natural, annealed condition. Such steel, it is known, has a state of rigidity and superior strength under stresses once applied, twice applied, and it may be thousands of times. There are situations, however, in which the stresses are repeated millions of times. Steel which fails in service does not commonly display the properties witnessed in the original tests. It fails in service without display of ductility showing neither elongation nor contraction of area comparable to the original test. Brittleness, almost extreme, is characteristic of service fractures. This circumstance leads to the mental association of internal strains, their localization, and their influence on the ultimate rupture of steel in service.

Heat treatment admits of being employed covering a wide range in temperature, with pronounced effects whether temperatures above or below the critical points are utilized. Certain phenomena are associated with the recalcitrant points, apparent in changes in structure. At plastic temperatures steel is hardly capable of retaining internal strains of magnitude and at such temperatures it possesses a very low tensile strength. Notwithstanding a diminished value of the modulus of elasticity, the strain between adjacent particles necessary to cause rupture while the steel is at a plastic heat, is of low degree. There is a feature in this connection which is worthy of consideration. It concerns the ability of the steel to endure differences in temperature at plastic temperatures with special reference to the interior portions of the steel. A state of cubic extension is set up at certain stages in the cooling of steel shapes; cooling strains of tension then act simultaneously

in three directions. The result may be a separation or shattering of the interior metal as witnessed in the case of steel rails with shattered zones in the head and at the junction of the web and base, or the steel may be left in a state of strain without actual rupture having been reached.

Ordinary cooling of forged or rolled shapes in a way constitutes heat treatment and internal strains may be thus introduced which are equivalent to stresses amounting to thousands of pounds per square inch. Quenching from comparatively low temperatures has been tried to introduce internal strains in hollow forgings. Internal strains were introduced at the bores of tube forgings equivalent to stresses of compression from 30,000 to 40,000 pounds per square inch. A favorable disposition of internal strains was thus accomplished for the resistance of interior pressures in thick hollow cylinders, provided subsequent use did not involve exposure to high temperatures. In a gun, however, exposure of the bore to the temperatures of combustion of powder gases at once annulled the initial advantage of the internal strains. The metal at the bore of a gun acquires a state of internal tension as the result of firing a few rounds. Heat treatment of this kind to improve the elastic resistance of the tubes of guns was a futile effort. Service conditions effaced the results which had been accomplished by the operation of quenching. Quenching from the bore of the powder chamber of the barrels of small arms was so drastically performed that the metal acquired a state of extreme hardness, leading to premature bursting of the barrels.

In the heat treatment of large forgings, hollow boring generally is stipulated. This is done in recognition of the introduction of intense internal strains by the operation of quenching. Heat treated driving axles have been put into place in which the internal strains caused a critical condition, the steel being in a state near to spontaneous rupture. Driving a plug in the end of such an axle, to afford opportunity of centering the axle in a lathe, overcame the residual strength of the axle whereupon it split into four equal sectors. This occurred in a hollow bored axle of about 10 inches diameter. Heat treated axles are received with distrust by some railroads since instances have been reported, seemingly well substantiated, where failure has taken place in driving axles at a very early period. Locomotives with heat treated axles have been delivered and in some cases the driving axles are reported to have ruptured before the engines had been taken over the tracks of the receiving company. Star-shaped fractures witnessed in heat treated steel rails at the junction of the web and base, partially destroyed the rail and rendered it unsafe for use.

It hardly can be gainsaid that subjecting steel to violent changes in temperature is not attended with elements of danger. Enormous forces are being dealt with, which must be kept under proper control. The rays of the sun sway colossal structures, buildings and bridges which sustain or suspend millions of pounds of material. A few degrees difference in temperature does this. The range in stresses involved in such engineering examples amount to but a few thousand pounds per square inch. In the heating and quenching of forgings of steel the mechanical equivalents of the heat effects are very great. It is to be hoped that more definite information may soon be acquired and become available concerning what constitutes the elements of durability to endure the vicissitudes of steel in service.

In conclusion does it not appear that points of similarity may be found between steel and good physique in a person, the resemblance extending to heat treatment of steel and highly developed physical culture in the

individual, with this sequel that an overstrained athlete while possessing great temporary prowess lacks endurance. Steel may be presented in any state, from one of internal repose in annealed metal to that of extreme internal tension in hardened metal, it then being on the verge of spontaneous rupture. Between these extremes there is a wide field within which the operations of heat treatment are conducted. The basic problem is found in the query: In what state does the steel best meet the conditions of service, which generally have to do with the endurance of long continued strains?

The heat treatment of steel precipitates this question.

THE BESSEMER PROCESS FOR MAKING STEEL

By Arthur P. R. Wadlund*

(A Paper Presented Before the Hartford Chapter)

Previous to about 1850, steel was made by both expensive and slow processes and no method was known whereby a large quantity of steel fit for commercial use could be produced. It will be remembered that crucible steel, for instance, is produced only in lots up to 100 pounds as a maximum, some lots being as low as 25 pounds. About that time an American named William Kelly and an Englishman, Henry Bessemer, worked out a method almost concurrently but independently for accomplishing quantity production. Although Kelly did not apply for his patent until 1857, almost two years after Bessemer's English patent was granted, his application was allowed on the grounds of priority, because he was able to prove that he worked out the idea as early as 1847. Lacking financial means, however, Kelly was unable to perfect his invention and after much litigation with Bessemer interests a settlement was made whereby Kelly dropped out of the game. At first Bessemer accidentally employed only Swedish iron which had a low phosphorus and a high manganese content and he was very successful in converting it. But although adopted by many manufacturers, the process failed when applied to English irons, which were high in their phosphorus and low in their manganese content, and prejudice and opposition to the method became so great among steelmakers that to save the process Bessemer was obliged to build a steelworks himself. His plant built in Sheffield began to operate in 1860. The history from that time on is merely a history of improvements which have been introduced in detailed mechanical arrangements and larger appliances.

Of all the processes for the purification of pig iron, that is the making of steel, the bessemer is the simplest. Essentially it consists of blowing air under pressure through a bath of molten metal contained in a vessel constructed of proper refractory materials. The principle involved is the same as with every process for making steel; the elimination of impurities by oxidation. To say every process relies on oxidation for the removal of these impurities is not quite correct in this age of electricity, for the electric furnace process involves both oxidation and reduction.

The distinction between these processes lies in the method of oxidation. In the bessemer, the oxygen for the oxidation comes from the air supplied by the blast. Oxidation is accompanied by heat and it is this heat resulting from the oxidation of the impurities that is depended upon to keep the metal in a fluid state.

At this point we must distinguish between the two Bessemer

* Metallurgist, Henry Souther Engineering Co., Hartford, Conn.

methods; namely, the acid bessemer and the basic bessemer, or Thomas Gilchrist method. This is necessary because the chemistry of the two processes is different. In the acid process only silicon, manganese, and carbon, together with some iron are oxidized; whereas in the basic process the silicon, manganese, carbon and phosphorus, together with some iron, and sulphur, are oxidized. Furthermore, in the acid process it is the oxidation of the silicon which is depended upon to furnish a large portion of the requisite heat, while in the basic it is the phosphorus which is depended upon. Thus in the acid process neither the phosphorus nor the sulphur are reduced and we must use a pig iron which contains no more of the two elements than the final product will permit, usually about 0.10 per cent phosphorus and 0.08 per cent sulphur as a maximum. In the basic process, on the other hand, we must use a pig iron of high phosphorus and a low sulphur content; low sulphur because it is eliminated only to a limited extent, and phosphorus over 2 per cent for the reason given above, that is, to furnish the requisite heat.

The bessemer process is therefore applicable only to two kinds of ores: First, those containing only a trace of phosphorus giving an iron suitable for an acid process; and second, those containing a high percentage giving an iron containing two per cent or more of phosphorus and suitable for the basic process. Many deposits of ore exist in different parts of the world which are intermediate between these classes and which give an iron ranging from 0.1 up to 2 per cent. Although these ores are not suitable for either form of bessemer process, it often happens that an iron which contains too little phosphorus for the basic converter can be used in admixture with an iron that contains a surplus. When this is impracticable such irons can be used for steel only in the basic open-hearth furnace.

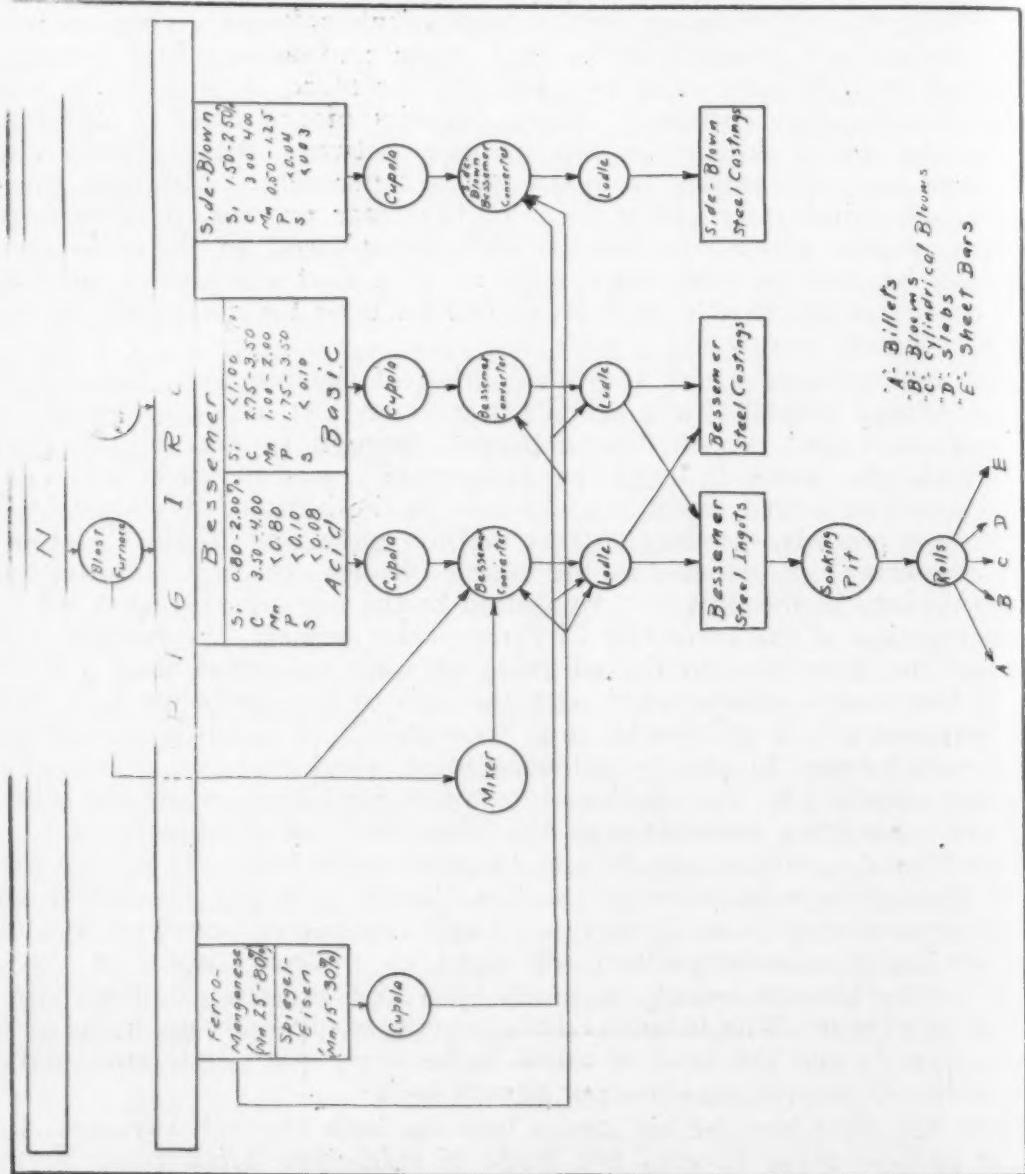
The apparatus in which the purification of the pig iron takes place is a pear or egg shaped object called a converter. At first the converters were stationary and the air was delivered through tuyeres in the side, from which the name "side-blown converters" was derived, with the finished metal delivered through a tap hole in the bottom. Owing to the difficulties in quantity production this method gave way to the "bottom-blown converter" in which, as the name implies, the air is admitted through tuyeres in the bottom. Evolution in the bessemer process led to the construction of the converter in three parts: namely, the bottom, the body, and the nose, also to the adoption of a tilting rather than a fixed unit. If the nose is symmetrical with the axis of the converter it is said to be "concentric"; if off center, it is "eccentric". The tilting converter is supported by two hollow trunnions, one of which has connected with it a pinion actuated by a toothed rack to allow for tilting, while the other forms the connecting link between the blast line and the blast box.

This blast box is situated directly beneath the bottom. It is very important that the bottom plate of the box should be easily removable so that the tuyeres may be easily examined and repaired or renewed, and at the same time it must be perfectly air tight, to prevent a waste of blast. The air for the blast is usually supplied by a high-pressure, double-cylinder blowing engine. The blast pressure, of course, depends upon the size of the converter and the head of metal to be overcome. It is customary to use about 20 pounds pressure per square inch.

From the blast box the air passes into the bath through tuyeres. In the acid process these tuyeres are made of refractory brick from 20 to

26 inches in length with holes from $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter. In the basic process the tuyeres are formed by ramming the refractory around wooden pins which are withdrawn after firing. The total tuyere area varies from 2 to $2\frac{1}{2}$ inches per ton of charge. The charge varies from 5 to 25 tons with 15 as a good average. At this point it might be well to mention that stationary and side blown converters are still used in units such as 5 tons or less, especially in steel foundries in America, and steelworks in Sweden.

The inside of the steel converter shell is lined with a highly refractory material, varying in thickness from 10 to 16 inches for different parts, being thickest on those parts subject to the greatest wear. The bottom, because it contains the tuyeres, is subject to the greatest hardships and therefore must be replaced most often. The life of a bottom depends upon the heat of the blows, the length of the blows, the blast pressure, and the amount of manganese in the pig iron. A bottom is generally worn away in about 12 to 15 blows, and sometimes fewer, while the lining of the body



of the converter lasts from 3 or 4 to 12 months or more. The nose lasts longer than the bottom but much less than the body. From what has been shown above, the advantage of making the vessel in three detachable parts is clearly evident.

In the acid process, the lining is made principally of silica, which is a highly refractory acid material. In England ganister rock, a high grade silicious material, and in America ganister, fire-stone, of mica-schist, with a thin layer of refractory fire clay laid between is used. These linings are thoroughly dried and brought up to a red heat before the converter is charged with molten pig.

The molten metal for supplying the converter may be (1) melted in cupolas, (2) taken direct from blast furnaces, or (3) taken from the latter and passed through a mixer before finally passing into the vessel. If, according to the first method, the molten iron is taken from the cupola, it may be poured directly into the converter by runners; it may be poured into a ladle on the same ground level as converters; or it may be tapped into a ladle on the ground level and the ladle then raised and the metal poured into the converter. From an economic point of view, both as regards labor and fuel, the ideal method is the second named, that is, to take molten iron direct from the blast furnace to the converter and so save the cost of remelting in a cupola. Owing to the irregularity of composition of such metal it has been discontinued in most cases.

To get a metal of more uniform composition it is almost universal practice to resort to the third method. For example, the molten iron from a number of furnaces is poured into a large vessel known as a mixer or receiver, as stated. These mixers have a capacity as high as 1200 tons and are made of steel plates riveted together and lined with silicious material, so constructed that they may be tilted and the iron poured from them into the converter. When receiving a charge the converter is always in the horizontal position.

Immediately after the vessel has received its charge, the blast is turned on under a pressure sufficient to prevent the metal not only from flowing into the tuyeres, but also to force the metal through the liquid. The converter is then racked to the vertical position and the blow commences which starts the chemical action between the oxygen of the air blast and the various ingredients.

The blow may be considered as divided into three stages or periods. First, the slag forming period; second, the boil; and third, the finishing period. During the first period the greater portion of the manganese and silicon are oxidized and unite with some oxide of iron—which is simultaneously produced—to form a double silicate of iron and manganese slag. Under normal conditions carbon is not appreciably oxidized until a considerable portion of the silicon has been removed. Such carbon as is oxidized passes off as carbon dioxide. This period is marked by an irregular violet colored flame at the mouth of the converter, gradually becoming more steady and then changing to a yellow color as the temperature of the bath increases.

After 5 or 6 minutes the carbon begins to oxidize rapidly and the bath being very fluid owing to the high temperature produced by the combustion of a relatively large proportion of silicon, the second period known as the boil commences. During this period the oxidation of silicon and manganese continues and a greater part of the carbon is also removed, mostly in the form of carbon monoxide, the percentage of carbon dioxide

forming rapidly decreasing. It is the formation and escape of carbon monoxide which causes the violent agitation of the bath and is attended with a very large flame issuing from the mouth of the converter, also with the ejection of considerable quantities of metal and slag. During the last period, the small amount of silicon left and the remainder of the carbon are oxidized, the latter to carbon monoxide. At the end of the boil the flame at the mouth of the converter rapidly contracts and the final disappearance of carbon is marked by the drop of the flame which indicates that the blow is complete. The vessel is immediately turned down and the blast shut off. In all, less than 20 minutes have elapsed. It is the judgment of the blower which is depended upon entirely to say when the blow is completed.

As was stated the phosphorus and sulphur in the metal are not eliminated. This is because the acid slag will not dissolve them even if they become oxidized. For this reason the percentage of these impurities increases slightly during the blow because their actual weight remains the same while the weight of the bath decreases. For instance, the total loss during a blow will amount to something like 8 to 10 per cent of the charge. Nearly half of this is oxide of iron and manganese which can be recovered by using them in the blast furnace.

The composition of the metal at this stage is about as follows:

Carbon	0.03-0.10 per cent
Manganese	trace-0.06 per cent
Silicon	trace
Sulphur	0.03-0.06 per cent
Phosphorus	0.08-0.10 per cent

If this metal were cast into ingots and rolled, it would be red short, that is, it would crack when rolled at a red heat. To overcome this red shortness a recarburizer is added. When mild or dead soft steel is being made ferromanganese or ferro, the best grades of which it will be remembered contains about 80 per cent manganese—usually is employed. This is thrown into the converter cold, or in some instances first heated to redness. When a high carbon steel is required, such as rail steel, spiegel-eisen or spiegel containing about 30 per cent manganese—in the best grades—is used. This is always melted in a cupola and added in a molten state either in the converter or the ladle. Spiegel is added in a molten state because the quantity required to give the requisite manganese in the finished steel would often be more than the bath of the molten metal would be able to melt.

Although the percentage of manganese is very different for ferro and spiegel, the carbon is nearly the same. Consequently, the addition of say 100 pounds of an 80 per cent ferro and 400 pounds of a 20 per cent spiegel, although giving the same amount of manganese, would give very different amounts of carbon, the latter four times the quantity of the former. From this it is evident that when the carbon is to be raised without increasing the manganese to any considerable extent, it is cheaper to use a large quantity of spiegel rather than a smaller amount of more expensive ferro. Anthracite coal, ferrosilicon (10 per cent silicon), and pig iron are also used in special cases as recarburizers. In addition to recarburizing, the recarburizer deoxidizes; that is, any iron oxide which is held is oxidized by the manganese and carbon. In the former case the oxide of manganese goes into the slag and in the latter case the carbon monoxide goes off as a gas producing a "boil" which requires precaution-

ary measures. This reaction is usually referred to as the spiegel or ladle reaction.

If the recarburizer has been added in the converter, the vessel is tilted beyond the horizontal position and the metal poured into a ladle. This ladle is then taken to the pouring platform. Here the teeming hole in the bottom of the ladle is opened and the ingots, or castings, poured. It should be noticed that in this operation of casting, the metal is teemed, whereas it is poured in the case of the converter and mixer. The reason for this is that we are not much concerned with the disposition of the slag, except when a finished or semifinished product is concerned, such as these castings or ingots mentioned.

If the recarburizer is not added in the converter it is added in the ladle. After the action has ceased, the ladle is brought to the platform and the ingots or castings poured as before. When castings are made we have a finished product and reach the end of the process. On the other hand, when ingots are poured, they must go first to a soaking pit and then to the rolling mill before the finished or semifinished product is produced.

Before passing to the basic process, let us examine the ingot molds. These molds are made of cast iron, the shape of which may be almost any convenient form or size, the purpose for which the steel is required being the determining factor. Ingots may be either top poured or bottom poured. Moderate sized ingots, say 10 inches square, are generally top cast. Bottom casting usually is employed only when a large number of small ingots are desired. The tendency of late years, however, has been to cast larger and larger ingots and cog down to blooms in the mill, finally rolling these to the required sections.

Before going to the mill, the ingots must be stripped of their molds. For this purpose the ingot stripper is used and is a very important adjunct. There are many forms of strippers, but perhaps the simplest and most used is the one which consists essentially of three rams, the outside rams pulling up on the molds to which they are attached, while the center ram acts as a plunger to hold the ingot down. The stripper not only saves a considerable amount of labor, but also reduces the cost of molds which would be short lived when pounded with the sledge. As it is, a mold stands only 100 casts at the most, 50 being a good average.

Let us now take up the basic process. We are all familiar with the quotation that "necessity is the mother of invention," and surely this applies to the invention of the basic bessemer process. As has been shown, the acid process removes no phosphorus and we have also seen that there are large ore deposits from which to produce a pig iron high in phosphorus. It was the utilization of this pig iron to which Sidney Thomas with the assistance of his cousin, Percy Gilchrist, lent his indomitable energy, ultimately both successfully, and completely solving the problem in about 1875. As a result the basic bessemer process usually is spoken of as the Thomas-Gilchrist process.

The secret lay in the substitution of a basic for the acid lining and the addition of a basic flux. Thus the silicious material used in the acid process is replaced by a lining of shrunk dolomite or other basic material rammed with anhydrous tar, and the basic material added is lime. The lime allows the formation of phosphate of lime which is not decomposed by metallic iron at the high temperature of the converter, and practically the whole of the phosphorus present is removed in combination with the lime

in the slag. If an acid lining were used rather than the basic, the acid lining would be attacked by the basic slag and eaten away before the end of the blow. Theoretically the basic lining plays no part in the reaction, only in so far as it provides a nonsilicious lining and enables a very basic slag to be formed by the lime addition.

The converter having been thoroughly heated, either by a previous heat or by means of a coal or coke fire as in the acid process, the lime is shoveled into the converter, which is in the horizontal position. Immediately the molten metal from the blast furnace, mixer, or cupola is admitted, the blast turned on and the vessel racked to the vertical position.

The various stages of the blow are identical to those described in the acid process until the drop of the flame which corresponds to a point where the carbon is reduced to about 0.05 per cent as has been said above. From here on comparison ceases. In the acid process we have seen that the vessel is immediately turned down and the blast stopped, but in the basic process the blast is continued for 3 or 4 minutes. This period is termed the "after blow" and is an absolute necessity because it is during this time that practically all of the phosphorus and some of the sulphur is removed, that is, we have the great heat forming period. The judgment of the blower is again depended upon for the determination of the end of the blow. His judgment as to the purity of the metal is based upon fracture tests on small samples.

In an earlier part of this article we accounted for the removal of the phosphorus. However, when we come to account for the behavior of the sulphur during the blow, we find it somewhat difficult because it is erratic. Sometimes considerable is removed, while at other times the elimination hardly is perceptible. The charges high in sulphur seem to have a greater percentage removed than those low in this element. The exact reactions will be omitted because authorities differ. It might be stated, however, that the fluid basic slag is generally conceded to be the main factor in the elimination of sulphur and also that manganese, after the addition of either ferro or spiegel, seems to play some part.

In passing, it might be well for us to get an idea of the amount of lime required. This depends upon three conditions: First, the amount of silicon; because silicon which is oxidized during the first few minutes of the blow is acid by nature and would attack the basic lining if it did not have the lime to satisfy it, which means that in adding lime we must account for the silicon content of the pig; second, the amount of phosphorus in the pig, because the phosphoric acid (P_2O_5) which is formed reacts with the lime to form phosphate of lime; third, the quality of the lime, for it is self evident that it should be as free from silica as possible, in fact a content of more than 1.5 per cent is very undesirable. Taking all three facts into consideration, it is necessary to add lime to the extent of from 14 to 20 per cent of the molten pig charged.

When ready to pour the metal, the following composition obtains:

Carbon	trace
Manganese	trace
Silicon	trace
Sulphur	0.05 per cent
Phosphorus	0.08 per cent

This analysis is not far different from the acid metal at the same stage. Following the same reasoning then, ferro, spiegel, etc. must be added, serving as before both as a recarburizer and deoxidizer. However,

this rebarburizer is not added in the converter because the carbon monoxide at this time is liable to reduce the phosphorus from the slag and cause a rephosphorization of the metal, inasmuch as carbon has a greater affinity for oxygen than has phosphorus. It is found best to pour off as much of the slag as possible before the metal in the converter is poured into the ladle where the rebarburizer is added. Basic slag is more fluid than acid slag because of the greater quantity of manganese in basic pig which is oxidized.]? From this point on there is no difference between the two processes.

If we compare the basic process with the acid process we will see that the former is much more expensive: First, because of a longer time in the blow; second, because at the end of the operation there is a delay to test for dephosphorization; and third, the greater cost of repairs, inasmuch as basic linings cost more than acid, but last only a fraction as long. However, this greater expense is partly equalized because basic pig is cheaper than the acid pig at least in the United States and also because high phosphorus slag may be sold as a fertilizer. In this country the basic process is no longer in operation, except to a very limited extent. The Germans on the other hand, with their immense deposits of high phosphorus ores of the Minette district found this process of incalculable value.

CARBONIZING AND CARBONIZING MATERIALS

By H. B. Knowlton*

(A Paper Presented Before the Tri-City Chapter

Carbonizing steel is the process of adding carbon. Steel may be carbonized during its manufacture, or it may be partially carbonized in the case hardening process. In this article only the carbonizing that forms a part of the case hardening process will be considered.

Steel may be case carbonized by any one of three ways: (1) By immersing the steel in a melted bath of cyanide or some similar bath. Sprinkling with a cyanogous material is really one phase of this same method. (2) By packing the steel in boxes with some solid carbonaceous material. (3) By gas carbonizing.

Cyaniding is one of the oldest or most commonly used methods. In general, it is used only in the production of very thin cases. It is known that the cyanides tend to break down under heat and yield cyanogen or some derivative of cyanogen. Cyanogen is a compound containing carbon and nitrogen. It has been believed generally that when cyanogen reacts with the steel, the carbon combines with the steel and the nitrogen liberated has no actions at all. It is worth noting, however, that G. R. Brophy and Miss S. B. Leiter of the General Electric Co., Schenectady, N. Y., presented a paper at the Philadelphia convention on "The True Action of Cyanide in Case Hardening Steel," in which they showed that the nitrogen of the cyanide did combine with the steel. This paper was published in the March issue of TRANSACTIONS. The authors claimed to have produced steel file hard, which contained only 0.30 per cent carbon at the surface.

In this steel they found large quantities of nitrides of iron, that is, combinations of nitrogen and iron. Hence, they argue that it is the nitrides and not the carbon in the steel that caused the hardness. They further bring out that steel containing nitrides is more brittle and more liable to surface

*Metallurgist, Case Hardening Service Co., Cleveland.

cracks than steel truly carbonized. If their work is correct, then it must follow that cyaniding has certain disadvantages and probably should be used only in the production of very thin cases on comparatively unimportant parts. Also, that it may be well to do away with the practice of reheating tools in cyanide.

Gas carbonizing is a comparatively new process. It has some advantages but at present seems to be limited to certain classes of work. The common type of gas carbonizing furnace is the revolving retort. The steel is placed inside of the retort and a current of gas is passed through while the whole is heated to a carbonizing temperature. As a general rule some carbonaceous material such as used in bone, leather, or old carbonizing compound, is charged into the retort along with the work. This is to cushion the work as it turns over and prevent mutilation of the hot pieces. By this method the time of carbonizing can be reduced greatly. It is worth noting that this method has been operated without the stream of gas, in other words, the work was heated in the revolving retort in contact with a solid carbonizing compound. Again the time of carbonizing was greatly reduced below that of the ordinary pack hardening method.

This method opens up a rather new field but it seems to offer great possibilities. In many cases the lack of a plentiful supply of good rich gas makes gas carbonizing impracticable but the use of the revolving retort with the proper kind of a compound may have great possibilities, but the author believes that a different compound should be used in this method than is customarily used in the pack carbonizing method.

In the pack carbonizing method, the steel is packed along with some carbonaceous material in boxes, and the boxes are heated for a number of hours. At first glance it would seem that the fundamental requirements of a carbonizing material would be that it contain a large amount of carbon. One of the questions frequently asked the makers of carbonizing compounds is "How much carbon does your compound contain?" While the question can be answered, the answer does not give much valuable information. For example, some grades of anthracite coal contain about 85 per cent of carbon, while bone contains only about 10-12 per cent carbon. Yet it is well known that bone is a much better carbonizer than anthracite coal. It may be well therefore before discussing the compounds to devote a little attention to the carbonizing process itself, and to see just what actually happens when a piece of steel is carbonized.

One of the theories that have been suggested, is that solid carbon diffuses into steel with which it is in contact. We know that there is solid carbon in contact with steel in the carbonizing boxes, but we also know that there is a limited amount of air in the boxes along with the carbon and the steel. We know furthermore that in the presence of air, carbon will burn when heated to a carbonizing temperature, thus forming a gas, either carbon monoxide or carbon dioxide. Thus the question is, whether it is this gas or the solid carbon that reacts with the steel and this is really a very important question.

To determine the answer, it is necessary to carbonize with solid carbon under conditions which will not permit the carbon to burn or form a gas. One of the early experimenters tried this. He heated iron wire in contact with pure carbon in a stream of hydrogen. He argued that the hydrogen gas would prevent the carbon from burning and that it would not enter into the reaction itself, however, his work has been disputed. It has been argued that he

should have carried out his experiment in a vacuum. But the fact remains that while he did produce a very slow penetration of carbon, the penetration was so slow that this method of diffusion of solid carbon into steel cannot be considered a satisfactory explanation of the rapid penetration of the common carbonizing compounds. We must seek some other action than the diffusion of solid carbon.

Another theory in which many believed was that all carbonizing was a form of cyaniding; that rapid carbonizing was possible only with materials which contained cyanide or would form cyanogen when heated. It was argued that any compound that contained both carbon and nitrogen might form cyanogen. This would include such materials as bone and leather which were known to be rapid carbonizers, being better than charcoal or coal which contain a greater amount of carbon. Without going into the discussion as to whether the forming of cyanogen is the explanation of the action of bone and leather in carbonizing, let it be said that just as rapid penetration has been produced by materials which could not possibly form cyanogen. Giollitti showed for example that he could do good carbonizing with CO and CH₄ gases.

Most of the commercial carbonizing today is done with solid materials which could not be expected to form cyanogen. Thus while the formation of cyanogen may sometimes take part in carbonizing, it is not a necessary condition. Furthermore as already mentioned, if Mr. Brophy's work is correct, cyanogen may actually nitrogenize instead of carbonize the steel. It may be just as well to stay away from the compounds which contain nitrogenous matter. This is not said to criticize any compound on the market for as far as the writer knows, all of the makers of carbonizing compounds have already discarded the use of nitrogenous matter in the manufacture of their compounds.

The last theory and the one most commonly accepted now, is that the carbon burns to form a gas, carbon monoxide, and that this gas reacts with the steel. The carbon combines with the steel to form a carbide, cementite. Among other conclusions Giollitti states that, "All other things being equal, the concentration of carbon in the cemented zone increases when the quality of pure carbon monoxide which comes into contact with a unit surface of the steel increases." His data also shows that the depth of penetration also increased.

According to this theory a carbonizing to be efficient should yield as large an amount of carbon monoxide as possible when it is heated to the carbonizing temperature. This probably explains why coal which is slow burning is not as satisfactory a carbonizing material as charcoal which burns faster and consequently forms more gas. The organic materials such as bone and leather probably decompose somewhat at the carbonizing temperature and yield products which readily burn to carbon monoxide.

The acceptance of this theory is liable to lead to a rather dangerous conclusion—that it is not necessary for a carbonizing compound to be uniform; and that the gases will circulate evenly through the box and produce even carbonizing so far as one box at least is concerned. To prove that such is not the case, the author wishes to cite a personal experience. Several years ago he tried to make his own compound, using a formula derived from the analysis of the commercial material that he was then using. The method of manufacturing the home-made material was necessarily rather crude and probably the product was none too uniform. This material was run in direct

comparison with the commercial compound. Three test pins were placed in the top, middle, and bottom of each pot. After carbonizing, these pins were examined under the microscope for the depth of case and the distribution of the carbon, that is, for the depth of the different zones of the case. The results were as follows:

	Hyper-	Depth of Zones		
	eutectoid	Hypo-	eutectoid	Total
Pot No. 1 Bottom Pin	0.000	0.007	.032	.039
Pot No. 1 Middle Pin	0.000	0.017	0.036	0.064
Pot No. 1 Top Pin	0.000	0.017	0.042	0.059
Pot No. 2 Bottom Pin	0.007	0.021	0.031	0.059
Pot No. 2 Middle Pin	0.000	0.013	0.029	0.042
Pot No. 2 Top Pin	0.000	0.011	0.043	0.054
Pot No. 1B Bottom Pin	0.002	0.019	0.025	0.046
Pot No. 1B Middle Pin	0.007	0.012	0.034	0.046
Pot No. 1B Top Pin	0.000	0.015	0.038	0.053
Pot No. 2B Bottom Pin	0.005	0.015	0.028	0.048
Pot No. 2B Middle Pin	0.002	0.016	0.036	0.054
Pot No. 2B Top Pin	0.011	0.009	0.029	0.049
Maximum total depth of case in home-made compound				0.059 inch
Minimum total depth of case in home-made compound				0.039 inch
Maximum total depth of case in commercial compound				0.054 inch
Minimum total depth of case in commercial compound				0.046 inch

Attention is invited to the fact that the maximum variation in the depth of case appeared on pins in the same pot. The variation was 0.020 inch in the case of the home-made material and only 0.008 inch with the commercial compound. Both materials were complex compounds involving chemical energizers such as will be discussed later. This shows the necessity for the compound's being uniform. Various other proofs of the same fact could be given, but this one was chosen because the data was complete and conclusive.

The question arises; why if it is the gas that does the carbonizing, does a nonuniform compound cause nonuniform results in the same pot? The answer may be that some parts of the compound are giving off gas more vigorously than others, and consequently the concentration of the gas is greater at the particular places where it is being the most vigorously generated. Or there may be something in the fact that gases are more vigorous in their action at the time they are being generated than they are later. This is a well known phenomenon; that nascent or freshly generated gases are more vigorous than the same gases after standing.

The above test showed the variation in the case, on pins that were several inches apart in the same pot. Assuming that it is the concentration of the gas or the action of the nascent gas, would it be possible for nonuniformity of the compound to cause a variation in the carbonizing in very small distances? For example, would it be feasible to attribute a soft spot the size of a grain of corn to a lack of uniformity of the carbonizing compound? Or could a small lump of clay touching a piece of steel in the carbonizing pot cause a soft spot? The author is inclined to believe that neither is possible and that small soft spots must be explained in some other way. It may be possible to have a difference in the gas concentration in different parts of a large pot, due to the different rates of generating gas of different parts of a nonuniform compound, and also due to the slow passage of the gas through the tightly packed com-

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results

Total
.039
.064
.059
.059
.042
.054
.046
.046
.053
.048
.054
.049
59 inch
39 inch
54 inch
46 inch
the depth
inch in
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bound from one part of the pot to another; but it seems highly improbable that there is a very great difference in the concentration inside of a small distance, say one inch or less.

This is answering the question from the theoretical standpoint. The same conclusion can be borne out by practical tests. For example, try to produce a soft spot at a given point by placing a small lump of dry clay against the piece at that point while packing it in the carbonizing pot. In some work on selective carbonizing it was found that it is not as easy to prevent the carbonizing gases from effecting particular parts of the steel, as is generally supposed. Copper plate and other thin protective coatings frequently fail to prevent carbonizing. In order to be sure that a given portion will not be carbonized, it must be covered with a coating that is absolutely impervious to gases at the carbonizing temperature.

These tests then lead us to the conclusion that a good carbonizing compound should yield a large quantity of carbonizing gas and that different portions of the same compound should generate the gas at the same rate of speed.

But these are not the only requirements of a good compound. The cost of the compound and the cost of new material that must be added to keep the compound up to strength, must also be considered. Another factor which is frequently overlooked is whether the compound adds anything injurious to the steel. The requirements of a carbonizing compound may be outlined as follows:

1. It must produce good results.
 - (a) Produce the desired per cent and distribution of carbon in the case.
 - (b) Produce uniform results.
 - (c) Must add nothing injurious to the steel.
 - (d) Produce good results at temperatures that are not harmful to the steel. A material requiring an excessively high carbonizing temperature, is undesirable.
2. It must be economical.
 - (a) Initial cost of compound per cubic foot should be low.
 - (b) Cost of upkeep of the compound should be low.
 - (c) It should give a rapid speed of penetration of carbon. When this is true the cost of operation of the furnaces will be comparatively low.
3. It should preferably be as noninjurious and as unobjectionable to the workmen as is practicable.

Some of these points are too obvious to need discussion, while others may be worthy of a little attention. Note that the cost must be figures per cubic foot. Compound is used by volume but is customarily purchased in weight. The different compounds vary in weight from about 17 pounds per cubic foot to over 50 pounds per cubic foot. One compound that is mostly saw dust is probably lighter than 17 pounds.

The cost of upkeep depends on the amount of new material that must be added after each run, either to keep the compound up to strength or to make up for shrinkage. Again it must be remembered that material is bought by weight but used by volume.

The question of adding injurious elements to the steel possibly is debatable. Bullens cites the work of Grayson which showed that by using leather he produced a case containing 0.55 per cent sulphur. The sulphur

content in the outer layer, 0.0025 inch, was 2.10 per cent. It is further stated that this high sulphur content of the surface causes softness and a skin brittleness or a tendency on the surface to chip off.

The use of cyanides and ferrocyanides in pack hardening compounds practically has been done away with, thus it is doubtful if there are any really poisonous compounds on the market. Some materials are rather disagreeable to the workmen on account of a large amount of dust.

Let us consider the different materials and see how well they fill the above mentioned requirements. Take first the older types of materials.

CHARCOAL. Charcoal probably is one of the first materials used. Wood charcoal is almost pure carbon with some moisture and a small amount of ash. The weight per cubic foot of granulated charcoal depends on the size of the granules and the kind of wood from which the charcoal was made. The size and kind of charcoal most frequently used in case hardening weighs about 19 pounds per cubic foot. It has a rather high shrinkage and it is not a very rapid carbonizer. It can be used over again but it has been stated that in the manufacture of blister steel it has been found that the charcoal is not as vigorous the second time as it was the first. Consequently it is necessary to add some new each time.

BONE. Bone carbonizes faster than charcoal and yields cases higher in carbon under the same conditions, but as bone contains only about 10 per cent of carbon it wears out very rapidly. Consequently, it is necessary to add a large amount of new each time, one half new bone being often considered absolutely necessary. Bone also contains considerable phosphorus, which is probably objectionable. Long tests have also proved that bone does not produce as uniform results as some other materials. This probably is due to the fact that the bones of all animals like the bones of the human change in chemical composition depending on the age and the condition of the animal. Bone weighs about 41 pounds per cubic foot.

LEATHER. Charred leather is another of the old standbys. It is very light, weighing about 17 pounds per cubic foot and has a rather high shrinkage. Leather has a good speed of penetration and produces cases high in carbon, but as mentioned by Bullens, leather may add sulphur to the steel. If it does that it is very objectionable. It has passed into disuse more on account of its high cost than any other factor.

COAL. Coal or coke probably have never been much used for carbonizing as they are both very slow. As will be shown, they have both been used successfully when mixed with other things.

So much for the raw materials that have been used in carbonizing. At the present time the socalled compounds have come into common use. The essential difference between these compounds and the raw materials is that the compounds are energized with certain chemicals, the idea being to increase the amount of carbon monoxide the compound will generate. Thus a chemical is added which when heated will give off either carbon monoxide or carbon dioxide gas. In either case in the presence of large amount of charcoal the final gas would be carbon monoxide. By the use of such chemicals wood charcoal and coke or coal can be energized until they will give a speed of penetration and yield a concentration of carbon in the case equal to that produced by bone or leather.

But if the chemical should spend itself with one time using, then more

chemical would have to be added after each run. Fortunately, however, there are some chemicals that are regenerative. For example, when they are heated they give off carbon dioxide but when they are allowed to stand exposed to the air after cooling, they will absorb the same gas, carbon dioxide from the air. In this way the chemical regenerates itself.

One successful compound on the market is composed largely of coal energized with lime. Most of the compounds use more or less charcoal. Some do not use coke, while a great many use more or less of this material. Nearly all the compounds utilize a chemical energizer. There is ground for some difference of opinion as to the proper amount of charcoal, coke and chemical respectively, some of the books give the following formula: charcoal 60 per cent and barium carbonate 40 per cent. So far as the writer has been able to learn, however, none of the commercial compounds in this country is made to that formula.

One peculiarity noticed is that increasing the chemical content beyond a certain point does not seem to increase the speed of penetration of the carbon nor yet does it increase the per cent of carbon yielded to the case. As proof of this the following tables are cited. These were taken from a test made about a year and a half ago.

In this test four different mixtures of charcoal coke and chemical were used. They have been labeled mixtures Nos. 1, 2, 3, and 4. Mixture No. 1 contains the least charcoal and least chemical and mixture. No. 4 contains the most chemical and most charcoal. The others lie in between. Outside of the difference in the relative proportions there is no difference between the four mixtures.

Four pots of each mixture were placed in a carbonizing furnace together, the pots being staggered so as to give each material an even change. They were all run the same length of time and every means was taken to make the test as comparative as possible. In the top and in the bottom of each pot a test piece was placed. At the conclusion of the run, the pots were allowed to cool down and the test pieces were sent to the laboratory. The total depth of the case was measured and the carbon content at different depths from the surface was determined by actual chemical analysis on shavings from cuts taken on a lathe. The first cut extended 0.007 inch from the surface and the following cuts went deeper by 0.010 inch each. The results were as follows:

Total Depth of Case on Test Pieces
Millimeters

Mixtures Nos.	1	2	3	4
1.0	1.2	1.3	1.1	
0.9	1.0	1.3	1.3	
1.2	1.3	1.2	1.3	
1.0	1.5	1.2	1.4	
1.0	...	1.3	1.2	
1.0	1.2	...	1.3	
1.1	1.3	1.4	1.3	
1.2	1.4	1.3	1.4	
Total	8.5	8.9	9.0	10.3
Average	1.06	1.27	1.29	1.29
Average in inches	0.042	0.050	0.051	0.051

Per Cent of Carbon on First Cuts in Pins from Bottoms of Pots
Millimeters

Mixtures Nos.	1	2	3	4
	0.93	1.05	1.12	1.15
	0.955	1.09	1.25	1.15
	0.89	1.09	1.13	1.09
	0.97	1.09	1.02	1.16
Total	3.745	4.32	4.50	4.50
Average	0.936	1.08	1.12	1.12

Per Cent of Carbon; Second Cut; Same Pins
Millimeters

Mixtures Nos.	1	2	3	4
	0.82	0.96	0.97	0.91
	0.82	0.93	1.01	0.96
	0.83	0.98	0.97	1.01
	0.85	0.98	1.00	1.09
Total	3.32	3.85	3.95	3.97
Average	0.83	0.96	0.987	0.99

Per Cent of Carbon on Third Cut; Same Pins
Millimeters

Mixtures Nos.	1	2	3	4
	0.63	0.74	0.63	0.70
	0.63	0.79	0.71	0.72
	0.68	0.71	0.86	0.82
	0.75	0.75	0.91	0.86
Total	2.69	2.99	3.11	3.10
Average	0.672	0.747	0.777	0.775

Attention is invited to the fact that while mixture No. 4 is richer in both charcoal and chemical than mixture, No. 3 it did not produce any better results. Also that Nos. 3 and 4 are only slightly better than No. 2, but are much superior to No. 1. Yet there is no more difference between the chemical analysis of Nos. 1 and 2 than there is between Nos. 2 and 3 or 3 and 4.

In other words, this leads us to the conclusion that there is a certain amount of chemical that should be present in a carbonizing compound, but that more chemical can be added without materially changing the results. The minimum amount of chemical depends on which chemical is used and also on the other ingredients of the compound. As a general rule, it is dangerous to use a compound in which chemical content is near the minimum. It is the practice of the manufacturers to stay above the minimum.

After deciding upon what chemical to use and the proportions of all ingredients of the compound, the next big question to determine is how the chemical is to be made an integral part of the compound. Of course, powdered chemical could be mixed dry with granulated charcoal and coke, but when

such a mixture is shipped, there is a great danger that the chemical will become separated from the rest of the compound. Also there is a danger of losing much of it in dust during handling. Certainly it is desirable to make the chemical an integral part of the compound. This is done in three ways: (1) By making pills; (2) by smelting the outside of the granules; and (3) by impregnating the chemical.

PILLS. The pill type compounds are made by grinding the various ingredients to dust. Then the different kinds of dust are thoroughly mixed together and with the help of some binder the whole mass is rolled into pills. These pills may or may not be coked. Whether the pills stand up on handling and during use or whether they break down into dust again, depends on the efficiency of the binder. The makers of pills claim that their product is more uniform.

SMEARED COMPOUNDS. Compounds of this type start with granulated charcoal or coke and smear the outsides of the granules with a mixture of the chemical and some binders. In this case the chemical is on the outside of the grains. How well it is held on depends upon the binder and the method of manufacture. The binder must be such that it will stand heating and still hold the chemical fast to the grains. Otherwise, after the first run there is simply a mechanical mixture of chemical in the form of dust and charcoal in considerably larger size grains. Again there would be the danger of separation and the formation of a nonuniform mixture.

SEMITI PILLS. Between these two types there is the class of compounds which are made using the grains of charcoal and coke as the nuclei and smearing them with a mixture of chemical and charcoal dust together with a binder.

IMPREGNATED CHEMICAL COMPOUNDS. This type of compound is made by impregnating the chemical into the pores of the charcoal or the coke as the case may be. The makers of these compounds claim that their compounds are more durable because the chemical is on the inside instead of the outside of the grains.

* * * * *

The above mentioned are the most common types of compounds on the market today and there are some very successful compounds in each class. It is also true that a novice at the game would be liable to make a very unsatisfactory compound no matter which method he chose.

It is worth mentioning that some compounds are made however, which, contain a great amount of oil. It is the claim that the hydrocarbons given off when these oils are heated, have a carbonizing action. Opponents of these materials, however, claim that the oil will all be vaporized and lost before the steel reaches the carbonizing temperature. However, if the pots are tightly sealed there may be considerable hydrocarbon vapor left in the pot after it reaches the carbonizing temperature.

This covers in a general way the principles involved in the manufacture of the modern commercial carbonizing compound. It is impossible, of course, to go into all the details with regard to formulas and the mechanical problems of manufacture, however, it is not as simple a problem as it might seem always to turn out a uniform compound on a large tonnage basis.

There are certain things that a carbonizing compound can do and there are some things that it cannot do. It adds carbon to the surface of the steel. The concentration of the carbon depends partly on the compound but this can be changed by subsequent heat treatments. The distribution of the carbon will be different in pieces that are slowly cooled as compared with those that

are quenched from the pot. Long continued heating at a temperature slightly lower than the carbonizing temperature will cause the case to sink in deeper and at the same time it will reduce the maximum carbon content at the outside. The compound may add sulphur, phosphorus or nitrogen to the steel and it is claimed that either of these will cause the case to be brittle.

The compound can not have any effect on the core of a case hardened piece. That is absurd. The properties of the core depend on the original steel and the heat treatment. Too much stress cannot be given the fact that the heat treatment following carbonizing has caused more trouble than all of the carbonizing compounds put together.

NEW MEMBERS' ADDRESSES OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J. represents Junior Member, and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

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 BENNETT, H. A., (M-6), Haughton Elevator & Machine Co., Toledo, O.
 BERTRAM, W., (M-5), 2624 N. Jessup St., Philadelphia, Pa.
 BIGELOW, R. E., (M-7), Geo. F. Blake Jr. & Co., Worcester, Mass.
 BONTON, L., (M-5), 2520 S. 15th St., Philadelphia, Pa.
 BROEMAN, Frank C., (M-4), 215 East Fourth St., Cincinnati, O.
 BURCHFIELD, M. I., (M-3), 1380 West 73rd St., Cleveland, O.
 BUSCH, Wilbur H., (M-4), Tate Jones & Co., P. O. Box 81, Dayton, O.
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 COTE, J. E., (M-6), 81 Hill St., Shelton, Conn.
 DALYRYMPLE, R. W., (M-7), Jones & Laughlin Steel Co., Pittsburgh, Pa.
 DAMICO, A., (M-5), 1744 E. Passyunk Ave., Philadelphia, Pa.
 FULLER, L. J., (M-7), Edgeworth, Sewickley, Pa.
 GENERAL LIBRARY, (Sb-10), University of Michigan, Ann Arbor, Mich.
 HAYNES, J. K., (M-7), 18 West St., Waterloo, N. Y.
 HEATH, A. D., (S-7), General Alloys Co., Merchants Bank Bldg., Indianapolis
 HOAGLAND, F. O., (M-7), Reed Prentice Co., Worcester, Mass.
 KISSAM, W. H., (A-3), 1105 Chester Ave., Cleveland, O.
 McBURNEY, J. W., (M-5), West Tech. High School, Cleveland, O.
 MILLER, J. R., Jr., (M-7), Jones & Laughlin Steel Co., South Side Works, Pittsburgh, Pa.
 MILNE, Alexander, (M-7), Jones & Laughlin Steel Co., Aliquippa Wks., Woodlawn, Pa.
 MONTAGUE, W. T., (M-7), 13 Clearview Ave., Worcester, Mass.
 MOULDER, W. J., (M-5), 1419 Porter St., Philadelphia, Pa.
 Ind.
 NELSON, George W., (M-5), 37 Sterling St., Worcester, Mass.
 SMITH, J. R., (M-6), 13 Washington St., Armor Park, Charleston, W. Va.
 SMITH, Wm. E., (S-7), Southington Hardware Co., Southington, Conn.
 STANTON, Wm. F., (M-4), J. A. Fay & Egan Co., Front & John Sts., Cincinnati, O.
 TAKAO, Shigezo, (M-8), Takao Iron Works, Kobe, Japan.
 WHITE, R. J., (M-7), 33 Alfred St., Springfield, Mass.

CHANGES OF ADDRESS

- ALLISON, Fred G.—from 1817 State St. to 162 Meredith Ave., Milwaukee, Wis.
 BIHLMAN, V. W.—from 32 Temple St., Springfield, Mass. to 361 N. Dawson St., Pittsburgh, Pa.
 BUGIE, Chas. A.—from Heller Bros. Co., Newark, N. J. to 77 Sunnyside Terrace, E. Orange, N. J.
 CARHART, W. H. C.—from Illinois Steel Co. to Interstate Iron & Steel Co., 104 S. Michigan Ave., Chicago, Ill.
 CLARK, Edward L.—from 925 N. 27th St. to Commercial Truck Co., Hunting Park & Rising Sun Avenues, Philadelphia, Pa.

- CROSSMAN, Leslie—from 15 Amherst St., Springfield, Mass., to 27 Richards St., Worcester, Mass.
- DALRYMPLE, M. W.—from University Club, Bethlehem, Pa. to 3738 N. 7th St., Philadelphia, Pa.
- DANSE, L. A.—from 882 Vermont Ave. to 2930 Pingree Ave., Detroit, Mich.
- DERRON, D. L.—from Trading Engineers, Inc., Rua Sao Joao 309, Sao Paulo, Brazil, S. A. to 290 Cote des Neigas Rd., Montreal, Canada.
- DIEDERICHE, Wm. J.—from 19 Howard St. to 278 Piedmont St., Waterbury, Conn.
- EVANS, H. J.—from 201 Western Ave., Aspinwall, Pittsburgh, Pa. to Ridge & 14th Ave., New Kensington, Pa.
- FELKER, A. W.—from Crucible Steel Co. of America, Cleveland O. to 1598 Elbur Ave., Lakewood, O.
- FRETZ, W. S., from 1105 Lehigh St. to 1107 Butler Ave., Eaton, Pa.
- GAFFNEY, Edwin P.—from Wheelock Lovejoy & Co., Chicago, Ill., to 140 Nassau St., New York City.
- GRAVLIN, Albert M-10—from 236 W. Genesee St. to 810 Park Ave., Syracuse, N. Y.
- HARR, F. H.—from 461 South Ave., to 625 Reynolds St., Elmira, N. Y.
- HOLLANDER, J. A.—from 2159 Lawn Ave., Norwood Sta., to 459 Lawn Ave., Cincinnati, O.
- HORINE, Karl M-6—from Commonwealth Edison Co. to 28 N. Market St., Chicago, Ill.
- LONGWELL, H. E. M-2—from Amer. Die & Tool Co., Reading, Pa. to 307 Wyman Park Drive, Baltimore, Md.
- McQUIGG, C. E.—from Electro Metallurgical Co., Niagara Falls, N. Y. to Union Carbide & Carbon Research Lab., Inc., Thompson and Mauley Sts., Long Island City, N. Y.
- MALACRIDA, J. T.—from 79 Elm St., West Haven, Conn. to 25 Lee St., Cambridge, Mass.
- MARLOWE, J. S.—from 536 Bankers Trust Bldg., to No. 7 Mayflower Apts., Indianapolis, Ind.
- MUENZEMAIER, Geo. A.—from Cincinnati Shaper Co., to National Lathe Co., 11-15 West Second St., Cincinnati, O.
- PIERCE, Paul—from P. O. Box 709 to 2015 Bellefontaine Ave., Indianapolis, Ind.
- PLATTS, J. C. M-11—from 9 Hartley St. H. O., Manchester, England, to 6A Fairfield Square, Droylsden, Manchester, England.
- REDDERSON, E. W. M-4—from 6405 S. Wood St. to American Car & Foundry Co., 2503 South Wood St., Chicago, Ill.
- REED, W. T.—from Geo. H. Smith Steel Castings Co., to 301 Ogelund Ave., Milwaukee, Wis.
- SMITH, Paul—from 122 E. Ohio St., to Box 561, Indianapolis, Ind.
- SQUIRES, John—from 4389 E. Chouteau Ave. St. Louis, Mo. to Old Colony Club, Detroit, Mich., care F. A. Curtiss.
- SULLIVAN, Leo. D.—from 1558 Penobscot Bldg. to 4843 Bellevue Ave., Detroit, Mich.
- SUTTON, Blair—from Crucible Steel Co. of America, to Sutton Abramson Eng. Co., 1901 Union Bank Bldg., Pittsburgh, Pa.
- WILKINS, Chas. M-3—from 6436 Blackston Ave. to 4001 Drexel Blvd., Chicago.
- WILLS, Wm. H.—from Braeburn Steel Co., Braeburn, Pa. to 437 South Ave., Wilkinsburgh, Pa.
- WHONNHART, Lewis—from Sanderson Wks. Crucible Steel Co. to 621 S. Wilbur Ave., Syracuse, N. Y.
- WOODWARD, A. F. M-4—from 621 G. St., S. W. Washington, D. C. to 827 Main St., Charleston, W. Va.
- ZONKER, L. W.—from 822 Belmont Ave. to 1528 Thurston Ave., Racine, Wis.

MAIL RETURNED

- AURELL, Carl, Billings & Spencer Co., Hartford, Conn.
- CHENEY, Arthur M., Standard Steel & Bearing Co., Inc., 5001 Lancaster Ave., Philadelphia, Pa.
- CONLON, Wm. F., 321 Bryant Ave., Syracuse, N. Y.
- GILMAN, R. L., 45 Read St., New Haven, Conn.
- GRIFFITH, N. S., 4040 Olive St., St. Louis, Mo.
- HANSON, H. E., 3616-64th Ave., West Allis, Wis.
- HYNDS, J. J., Care Coronet Phosphate Co., Coronet, Florida.

KALENDER, Louis, 92 Florida St., Dorchester, Mass.
O'CONNOR, F. P., 199 Stryker Ave., Woodside, L. I., N. Y.
RABB, F. C., 324 Bordon Ave., Syracuse, N. Y.
ROSEN, Joe, The Linograph Co., Davenport, Ia.
SMITH, R. H., 171 High St., Boston, Mass.
WILLIAMS, R. W., Sheldon Axle & Spring Co., Wilkes Barre, Pa.

Commercial Items of Interest

Research facilities and the development activities of American industries are to be described in the forthcoming revision of Bulletin No. 2 of the National Research Council, "Research Laboratories in Industrial Establishments of the United States of America." Only 300 such laboratories were listed in the first edition but it is hoped that several hundred new names will appear in the revision and that a more nearly complete reference list will thus become available. The general demand for the first edition of the Bulletin shows the wide interest in this subject, and the importance of having every laboratory which devotes even a portion of its time to research properly listed. This Bulletin will be published at an early date.

The Council requests information from directors of research who have not already supplied it. The following data are wanted: Name and address of firm and address of laboratory; name of director of research; number on laboratory staff (classified as chemists, engineers, bacteriologists, etc.); approximate proportion of time spent on research; chief lines of research; unusual features of equipment; research laboratory space; date of organization of research laboratory and annual expenditure for research. Confidential information is not desired. This material should be furnished to the Research Information Service, National Research Council, 1701 Massachusetts avenue, Washington, without delay.

A contract for two sheet, two pair and six annealing furnaces was recently given to the Surface Combustion Co., Inc., 366 Gerard avenue, Bronx, New York, by the International Nickel Co., 67 Wall street, New York. The equipment will be installed in the latter company's new plant at Huntington, W. Va. Frank I. Ellis, 2126 Farmers Bank building, Pittsburgh, is the consulting engineer for the new plant, acting through W. L. Wotherspoon, chief engineer of the International Nickel Co.

The United States Civil Service Commission announces an open competitive examination for assistant metallurgical chemist on Aug. 17. Vacancies at the naval ordnance plant, South Charleston, W. Va., and vacancies in positions requiring similar qualifications will be filled from this examination. The duties of appointees will consist of analysis of steel, iron, alloys and other metallurgical materials and will require ability to make quick test analysis of steel for the following elements: Carbon, silicon, manganese, sulphur, phosphorus, nickel and chromium. Full

details of the examination may be obtained from the Civil Service Commission, Washington.

Bulletin No. 230 recently distributed by the W. S. Rockwell Co., 50 Church street, New York, is a series of papers relating to principles governing industrial heating operations. The five papers included in the bulletin are: 1. Factors Governing Quality and Cost of Heat Treated Products. 2. Relation of Temperature Control to Uniformly Heated Product; 3. Selection of Furnaces; 4. Relation of Price of Fuel to Cost of Production; and 5. The Influence of Furnace Design on Quality and Cost of Product. Each of the papers are illustrated with sketches or charts. In preparing the bulletin the company has attempted to make each of the pages with its accompanying chart practically a paper in itself in order that it may be lifted and reprinted to good advantage. Other bulletins of a similar nature will be published by the Rockwell company from time to time.

Iron and Steel in Sweden is the title of a most comprehensive book published by the Jernkontoret or Iron Masters' Association in co-operation with the Aktiebolaget Svenska Teknologforeningens Forlag, Stockholm, Sweden. The book has been distributed widely in this country by the Swedish Chamber of Commerce of the U. S. A. This volume is intended to give necessary information to buyers of Swedish iron and steel. For the convenience of the user a number of sections are provided, listing both products and manufacturers, with a guide as to how to use these sections. The first few pages are devoted to a brief history of the iron and steel industry in Sweden and is followed by a sketch of the Iron Masters' Association, its purpose and work. Next is shown a map of Sweden with the location of iron and steel plants. This is followed by a list of producers listed according to products. A description of Swedish iron and steel works occupies the next 183 pages and is profusely illustrated with views of the various plants. The remainder of the book is devoted to advertisements and a complete index.

Electric furnaces and heat treatment of dies and forgings was discussed by E. F. Collins, General Electric Co., Schenectady, N. Y., at the eighth annual convention of the American Drop Forge association held jointly with the Drop Forge Supply Association in Chicago, June 22-24. Mr. Collins went into the subject briefly and pointed out the advantages of electric heating. Proper furnace conditions for heat treating die blocks were described by Dr. Trood, Tate-Jones & Co., Pittsburgh, his talk being illustrated by stereopticon slides.

A pneumatic truck for charging annealing ovens is described in an 8-page illustrated booklet recently published by the American Foundry Equipment Co., New York. This truck operates by a reciprocating type, air motor. The drive transmission comprises a standard motor truck differential the shafts of which carry a steel pinion in engagement with internal gears in the periphery of the two forward wheels. Air is supplied by a flexible hose connection. A throttling pedal controls the motor speed, and a hand lever the direction. Steering is by means of a standard motor truck hand wheel. With this truck short turns may be made.

(Continued on Page 36)

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice.

In addressing answers to advertisements on these pages, a stamped envelop containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

MECHANICAL ENGINEER—Age 33, married, 18 years experience as designer; machine shop foreman, chief draftsman, and efficiency engineer. Broad experience in designing of gas furnaces, special machinery, tools, jigs, fixtures, gauges and dies. Well acquainted with steel treating and hardening. Desires position where initiative and inventive ability along manufacturing lines are considered. Address 8-1.

SUPERINTENDENT OF TIME—In automobile plant. One year Govt. inspector on forge work, one year testing drop forgings and inspecting same, three years laying out forging machinery and taking time studies, also have taken time studies in assembling automobiles. Salary \$300.00 per month. Address 8-2.

POSITION WANTED—In metallurgical laboratory of heat treating room. 17 years practical experience in heat treating, specializing in tool hardening. No restrictions as to location. Reasonable salary. Address 8-3.

WANTED—Position as assistant hardener. Practical experienced man in case hardening and heat treating of all different makes of steel. Do not claim to be an expert but can deliver the goods. Salary \$25.00—\$30.00 per week. Address 2-8

WANTED—Position as metallurgical engineer in technical, executive or sales capacity. Ten years practical experience in research, physical and chemical testing, pyrometry, metallography, inspection, and specifications. Have installed heat treating plants and laboratories. Address 2-5

WANTED—Position as metallurgist or assistant, graduate of University of Minn., one and one half years with large tractor company, covering heat treating, chemical, metallographic and physical testing, during that period. Chicago territory preferred. Salary \$175.00 a month. Address 2-6.

WANTED—Position as salesman. Graduate of Carnegie Technical Institute. Student for 16 months with large steel company. Three years selling. Best of references. No preference as to location. Address 2-7.

GENERAL SUPERINTENDENT OR PRODUCTION MANAGER—8 years as general superintendent with large manufacturing firm. Expert on manufacturing firm arms and munitions, machinery and small interchangeable parts. Eastern location preferred. Address 4-1.

CHEMIST OR METALLURGIST—6 years as chemist and three years as chief chemist and assistant to the metallurgist. Cleveland location preferred. Address 4-2.

SALESMAN—Selling steel or metallurgical supplies. Knowledge of Spanish. Willing to travel. Have been chief metallurgist for large Eastern firm. 7 years experience in heat treating of carbon, alloy and high speed tool steel, and general production work. Experienced in metallography, physical testing, pyrometry, and analysis. Best of references. Address 4-3.

SALESMAN—Have had 6 years in chemical and physical laboratories of tool steel concerns. 3 years in charge of heat treating tool steels. No preference as to location. Wages \$175.00 a month. Address 4-4.

FOREMAN OR ASSISTANT FOREMAN—Practical, experienced in all around forging, blacksmithing and treating of steel. Experienced with tools used in shipyards and machine shops. Prefer location in Chester, Pa., Camden, N. J., or Philadelphia, Pa. Address 4-5.

METALLURGIST OR ASSISTANT METALLURGIST—College graduate. At present assistant metallurgist in large motor car company. Capable of handling heat treating, microscopic work, chemical analysis, and pyrometry. Desire Central or Western location. Salary \$250.00 per month. Address 4-6.

METALLURGICAL ENGINEER—Young, capable, energetic, with 11 years experience. Graduate engineer. Bureau of Standards for 7½ years. Erie Forge Co. for 3 years. Expert in pyrometry in steel plant, forge shop, open hearth and heat treating plants, metallurgy, investigations and research, planning metallurgical operations, heat treating carbon or alloy steels, and management, forge shop temperature scheduling, etc. Salary desired \$3000, or make your proposition. Answer 7-2.

METALLURGIST—Age 25, experienced in manufacture of steel from blast furnace to the finished, heat treated and tested product. Desire to form a connection with company now building up an organization where opportunity at present as the future shall predominate. Cleveland district preferred. Answer 7-1.

SUPERINTENDENT OF HEAT TREATING—Have had 12 years' experience as blacksmith and in heat treating. At present in charge of same in large automobile plant. Have installed equipment, and have some experience along mechanical lines. During war in charge of aircraft forging, heat treating and as metallurgist. Salary desired \$3600. Answer 7-1.

This qualification record will be printed in the "Men available" section of the Employment Bureau of the Transactions at a cost of 50c each insertion.

The money to cover this Charge should accompany this form.

QUALIFICATION RECORD—Strictly Confidential

Name _____

Address _____

No. of Years in
Grammar School?

Other Schools?

Experience:

Wages Desired?

Location Preferred

Kind of Position Desired

Back Numbers

We can supply the following:

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CONSISTENTLY
UNIFORM



When answering advertisements please mention "Transactions"

(Continued from Page 33)

Compressed air raises and lowers the steel tongs which carries the load and a convenient hand lever admits or discharges pressure to an air cylinder. The truck is described in detail and the illustrations show it at work.

Auxiliary equipment for storing, transporting and conditioning liquid fuel is described in a booklet issued by the George J. Hagan Co., Peoples Bank building, Pittsburgh. Among the opening pages is a reproduction of a blue print which shows the comparative costs of various fuels on a B.t.u. basis. Designs of oil storage tanks and electrostatic control of fuel temperatures in suction lines and tables of dimensions for electric driven pumping systems follow. The company recommends that pumps be furnished in duplicate sets. Two pages are devoted to an explanation and illustrations of relief valves, liquid fuel strainers showing cross sectional areas. Pulsometers, liquid fuel heaters, reducing valves and air blowers, are each explained by means of text, blue prints, tables and diagrams.

A small 48-page booklet just distributed by the Heller Bros. Co., Newark, N. J., discusses clay crucibles and special tool steels made by that company. Thirty-two pages are devoted to the specifications and characteristics of the various types. A number of illustrations are used showing the trade mark labels of the various brands, the standard cross sections of steel made and several manufacturing operations in the company's plant. The balance of the booklet is devoted to standard tables and useful information.

ELECTRICAL REFRactories FOR USE IN

Resistance Type Electric Heating Devices, including Electric Ranges, Steel Treating Furnaces, Enameling Ovens, Immersion Heaters, and Laboratory Equipment.

Our refractories are used to insulate and support the heating element, they are burned to 2500° F. during the process of manufacture and will not fuse or disintegrate under 2600° F. They are not injured by the application of water or acids while heated.

Our engineering staff with many years of practical experience stands ready to co-operate with you.

The Electrical Refractories Co.
East Palestine, Ohio

Our Refractories are used by the largest manufacturers of electric heating devices both domestic and foreign.

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